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(54) **MULTI-LAYER COATING FOR PLUNGER AND/OR PACKING SLEEVE**

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(51) **Int. Cl.**

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E21B 37/06 (2006.01)
E21B 23/08 (2006.01)
E21B 4/18 (2006.01)

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CPC ***F04B 53/166*** (2013.01); ***E21B 4/18*** (2013.01); ***E21B 23/08*** (2013.01); ***E21B 37/06*** (2013.01)

(58) **Field of Classification Search**

CPC F04B 53/166; E21B 4/18; E21B 23/08; E21B 37/06; E21B 12/02

See application file for complete search history.

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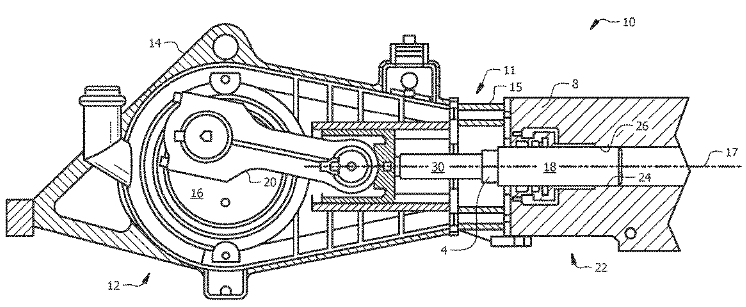
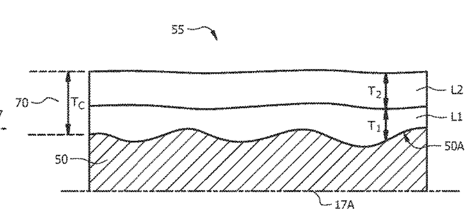
(57) **ABSTRACT**

A pump fluid end comprising: a reciprocating element disposed within a reciprocating element bore and having an outer surface; a reciprocating element packing positioned within the reciprocating element bore; and optionally a sleeve positioned within the reciprocating element bore and having an inner surface proximate the outer surface of the reciprocating element, wherein at least a portion of the outer surface of the reciprocating element and/or the inner surface of the sleeve is coated with a multi-layer surface coating comprising a plurality of layers including: a first layer in contact with the at least a portion of the outer surface of the reciprocating element and/or the inner surface of the sleeve; and a second layer disposed over at least a portion of the first layer; and wherein at least one of the plurality of layers has a different visual appearance and/or material composition than another of the plurality of layers.

22 Claims, 8 Drawing Sheets





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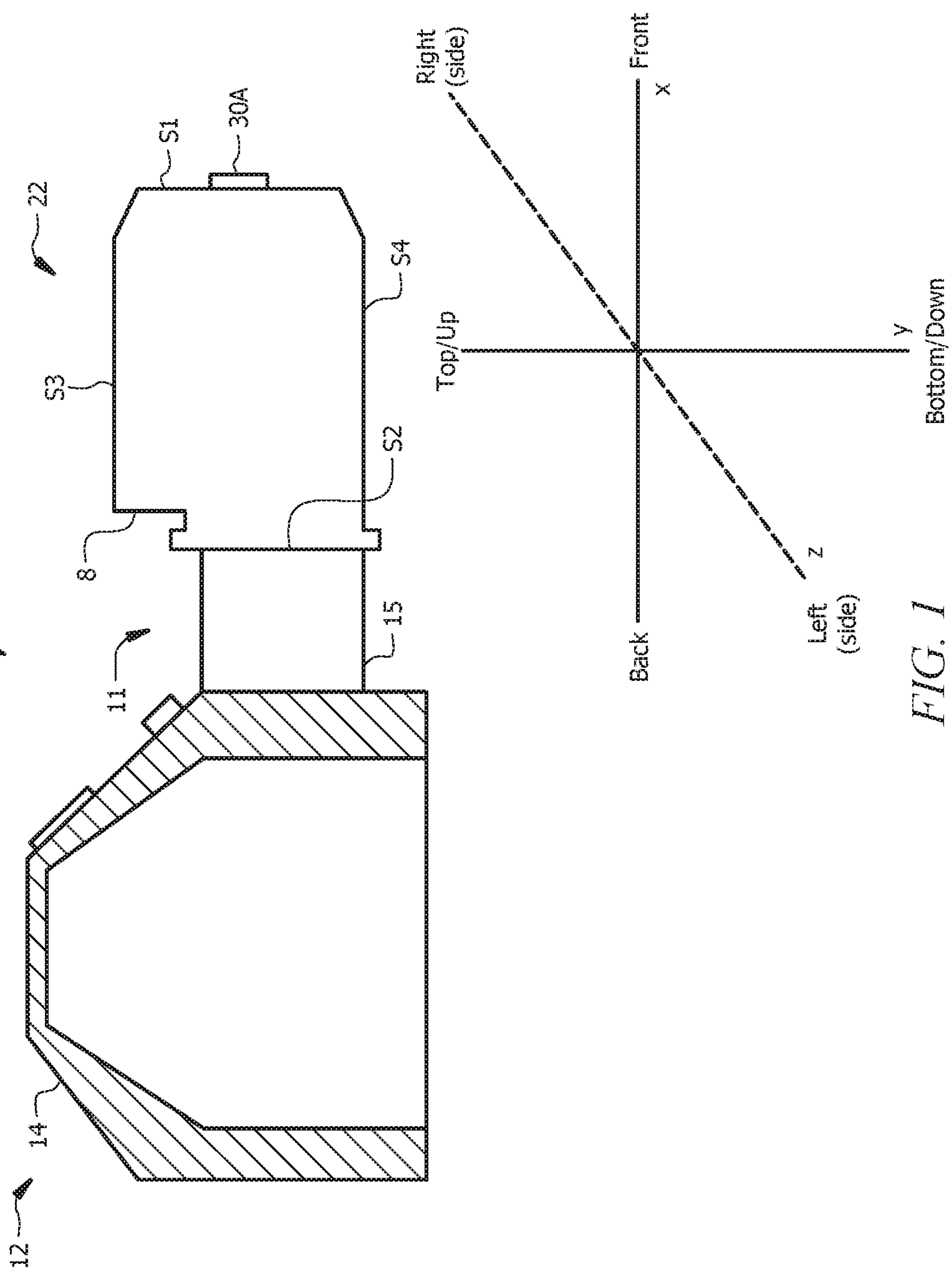

10
11
12
14
15
22
8
S1
S2
S3
S4
30A
Right
(side)
Front
x
Top/Up
y
Bottom/Down
Back
z
Left
(side)

FIG. 1

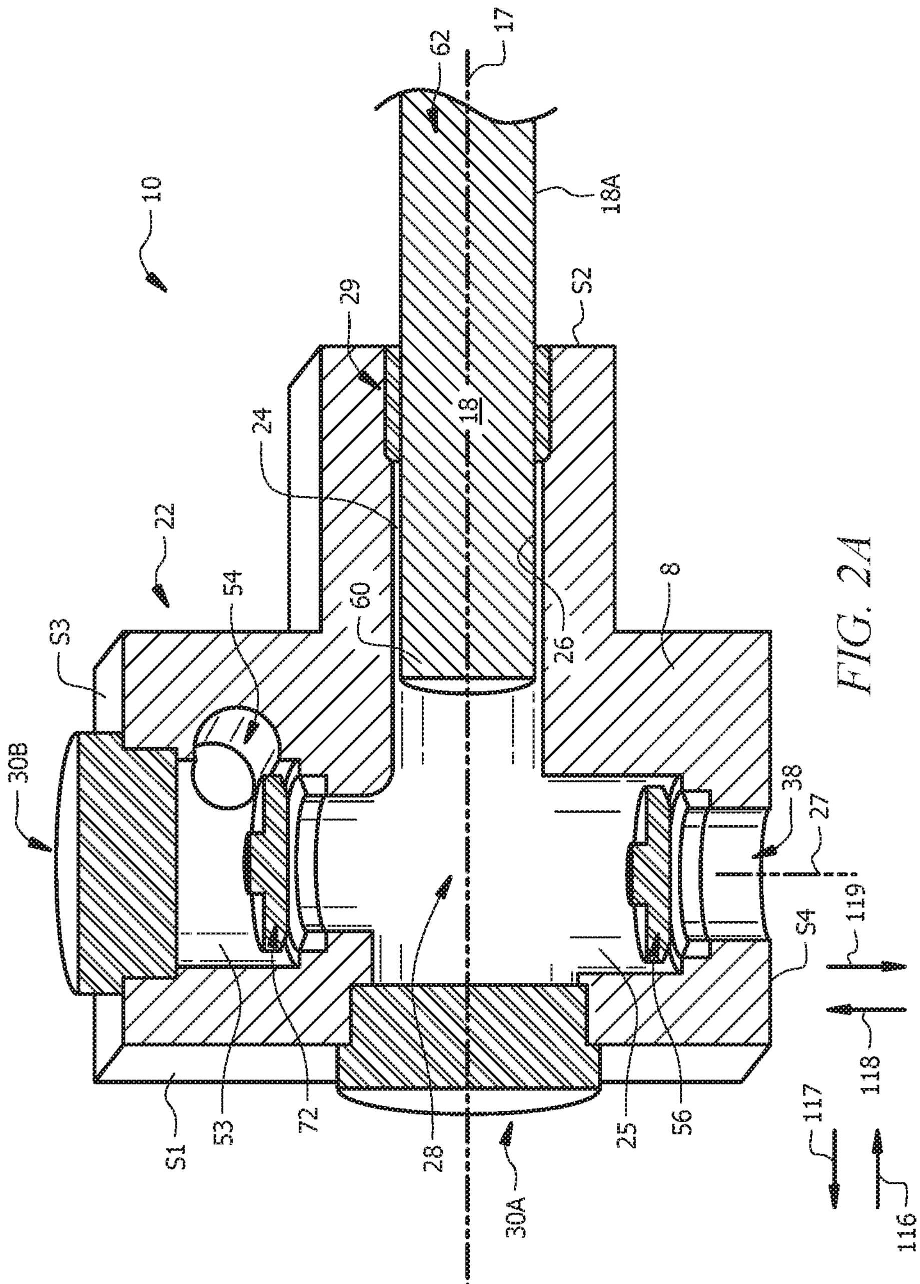
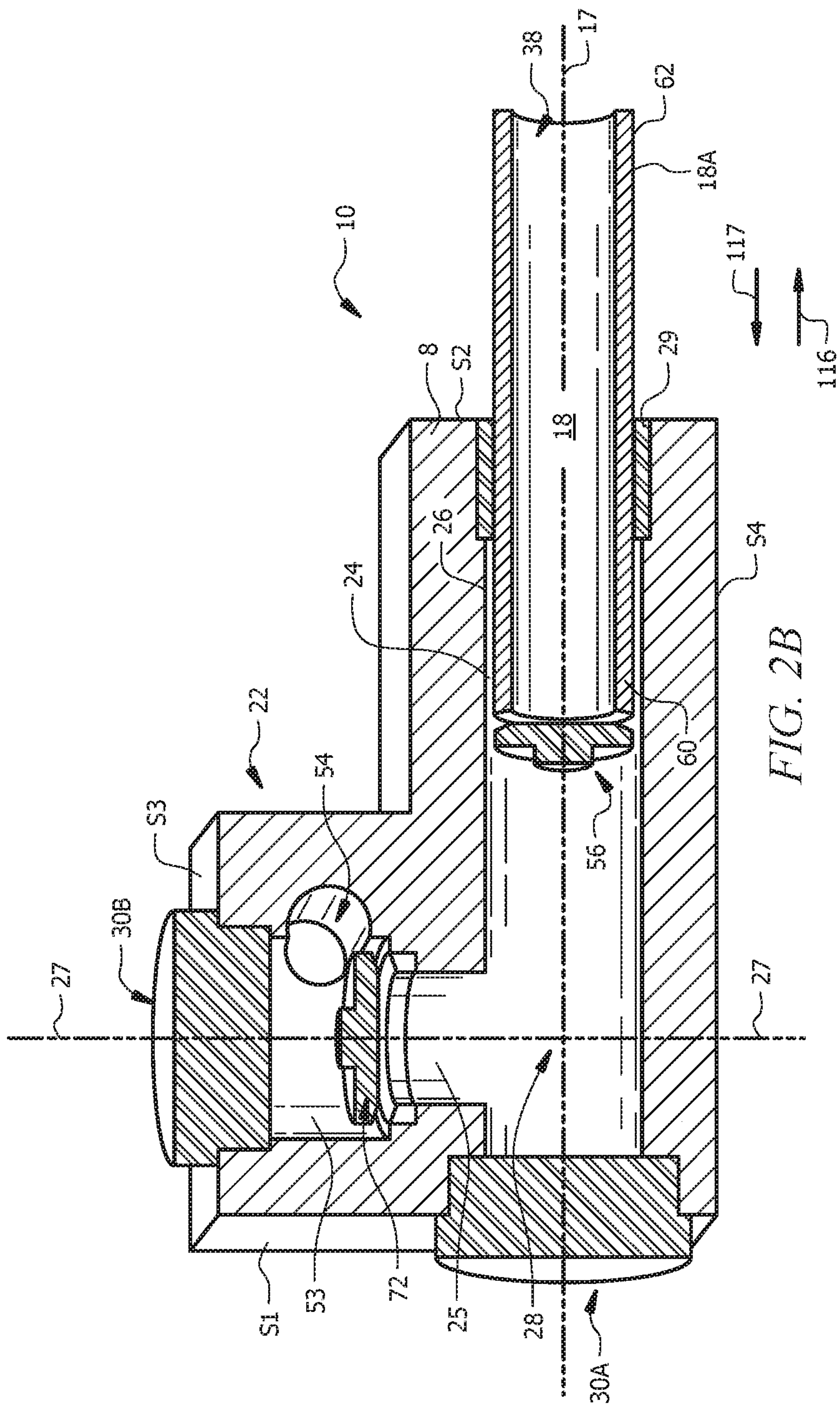

10
62
17
18A
S2
29
18
24
22
54
60
26
8
S3
30B
38
27
119
S4
118
117
116
30A
28
25
56
72
53
S1

FIG. 2A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17
62
18A
117
116
8
S2
29
18
26
24
S4
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56
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S1
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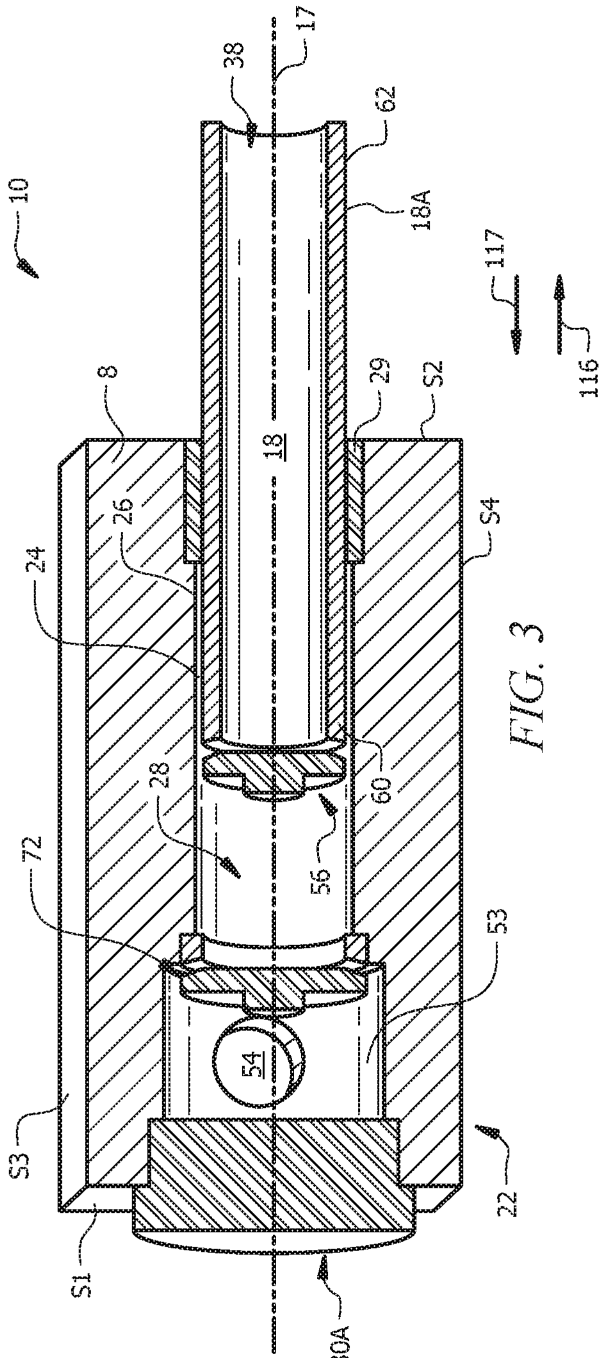
25
28
30A

FIG. 2B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38
17
62
18A
117
116
8
29
S2
18
26
S4
24
60
28
56
72
53
53
54
S3
22
S1
30A

FIG. 3

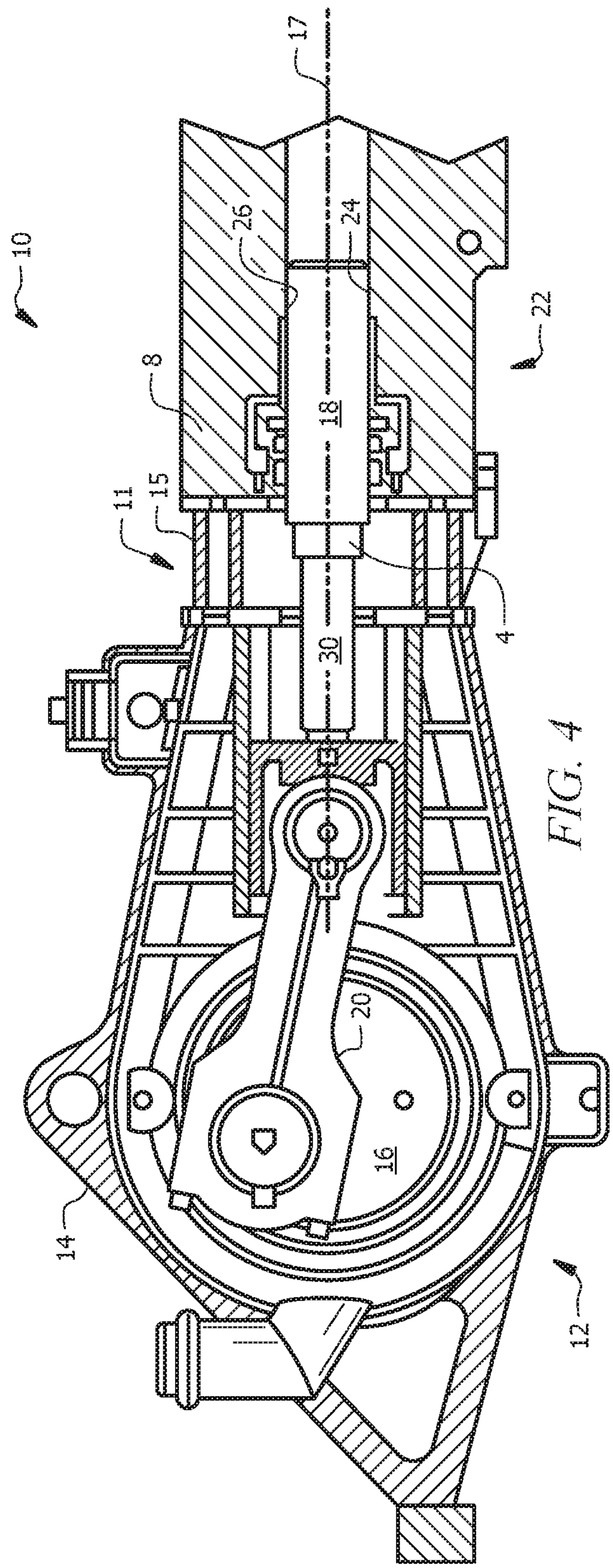


FIG. 4

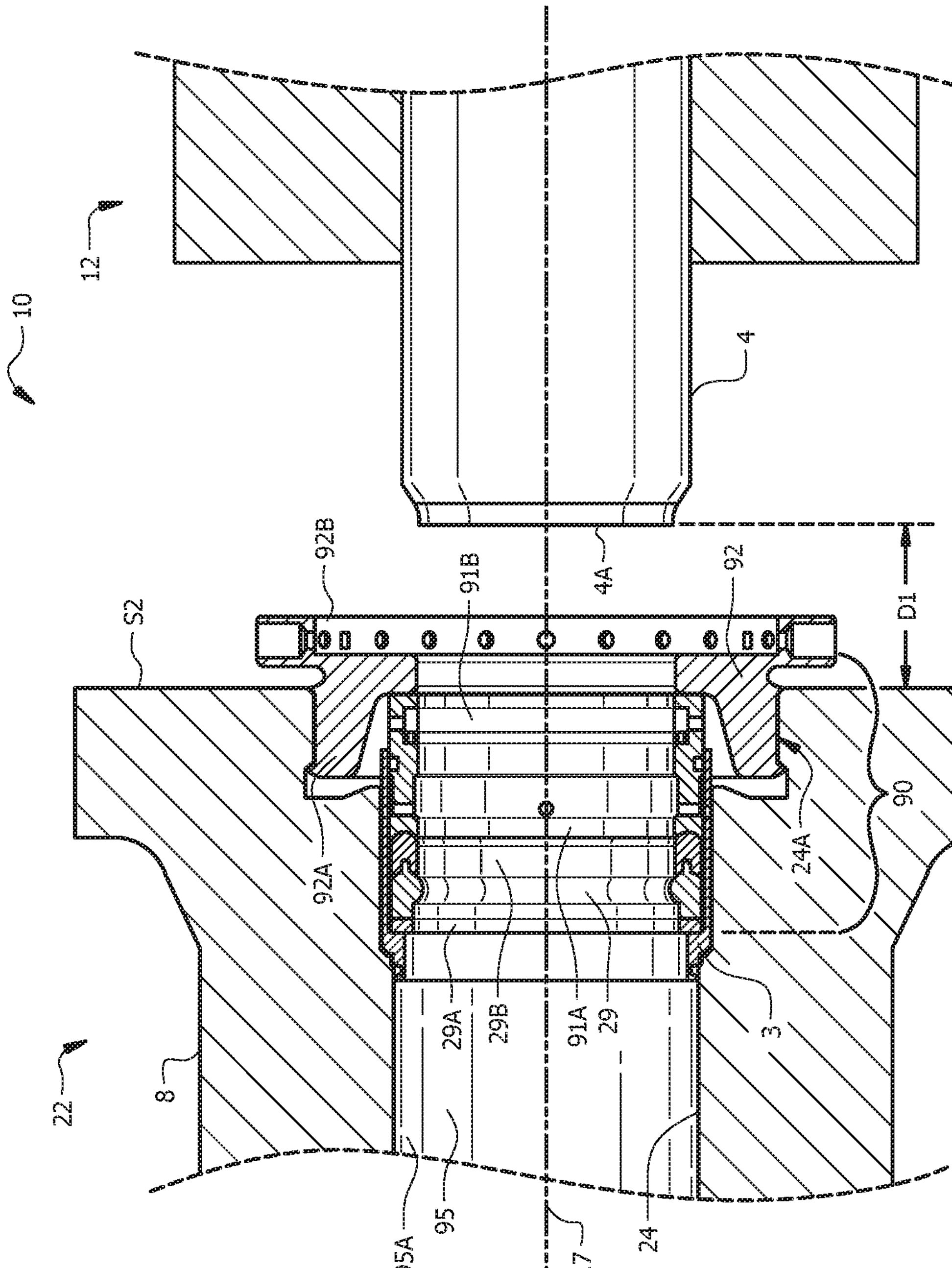

10
12
4
92B
91B
4A
92
D1
S2
90
24A
92A
3
29A
29B
91A
29
22
8
95A
95
17
24

FIG. 5

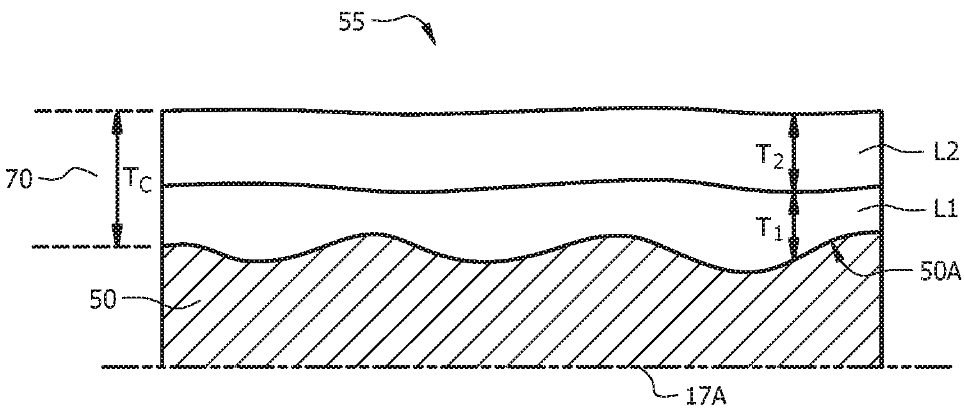
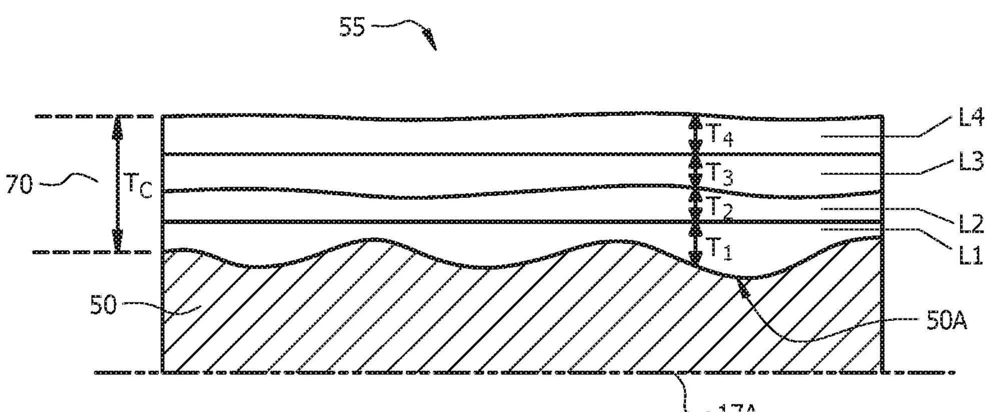

55
70
T_C
T_2
T_1
L2
L1
50A
50
17A

FIG. 6A


55
70
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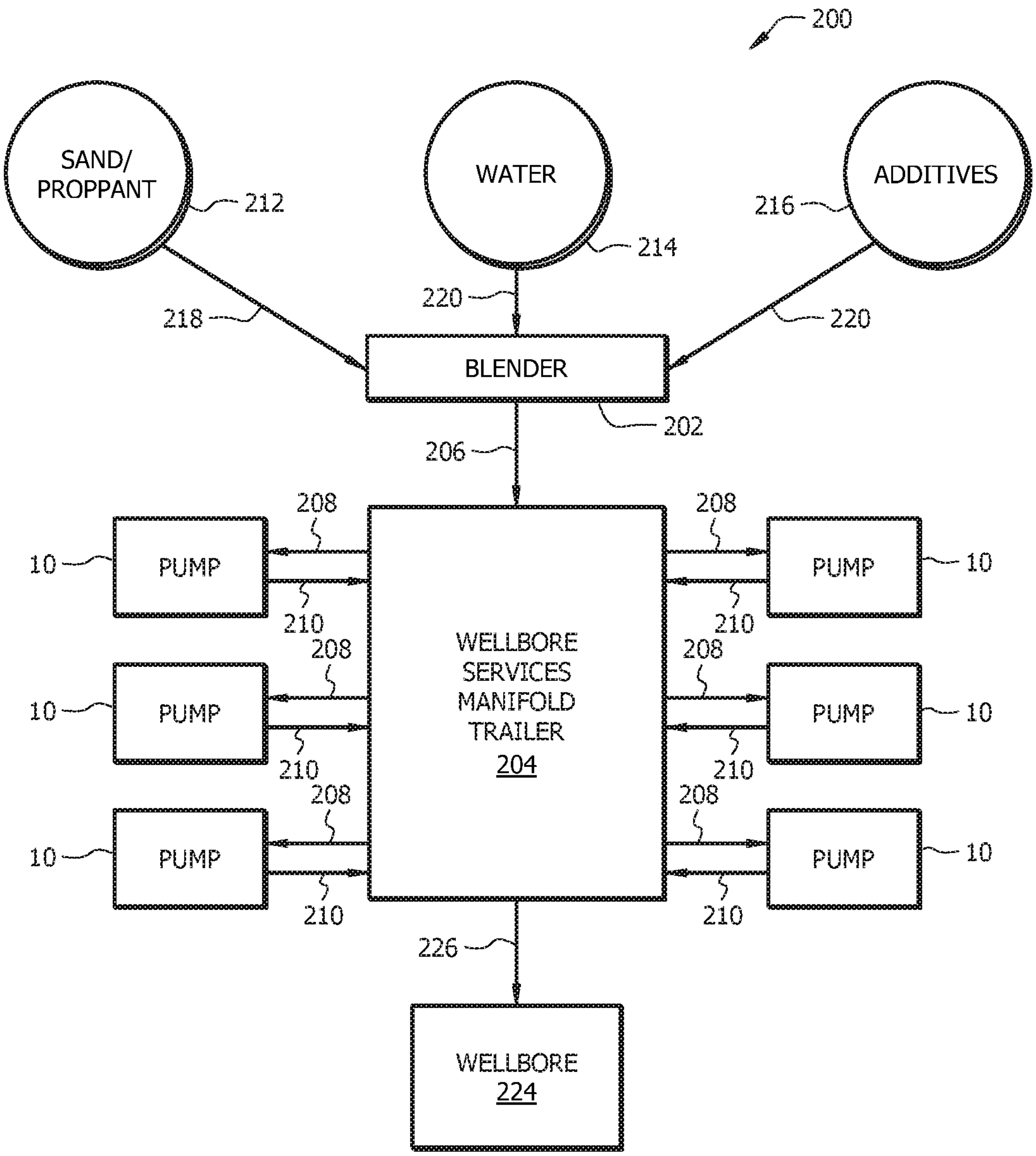
T_4
T_3
T_2
T_1
L4
L3
L2
L1
50
50A
17A

FIG. 6B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SAND/
PROPPANT
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WATER
214
ADDITIVES
216
218
220
220
BLENDER
202
206
208
210
PUMP
10
WELLBORE
SERVICES
MANIFOLD
TRAILER
204
226
WELLBORE
224

FIG. 7

MULTI-LAYER COATING FOR PLUNGER AND/OR PACKING SLEEVE

CROSS-REFERENCE TO RELATED APPLICATIONS

Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

REFERENCE TO A MICROFICHE APPENDIX

Not applicable.

TECHNICAL FIELD

The present disclosure relates generally to a method and apparatus for supplying pressurized fluids. More particularly, the present disclosure relates to methods and reciprocating devices for pumping fluids into a wellbore.

BACKGROUND

High-pressure pumps having reciprocating elements such as plungers or pistons are commonly employed in oil and gas production fields for operations such as drilling and well servicing. For instance, one or more reciprocating pumps may be employed to pump fluids into a wellbore in conjunction with activities including fracturing, acidizing, remediation, cementing, and other stimulation or servicing activities. Due to the harsh conditions associated with such activities, many considerations are generally taken into account when designing a pump for use in oil and gas operations. One design consideration may concern ease of maintenance, as reciprocating pumps used in wellbore operations, for example, often encounter high cyclical pressures and various other conditions that can render pump components susceptible to wear and result in a need for servicing and maintenance of the pump.

Accordingly, it is desirable to provide a pump fluid end comprising a multi-layer coating on one or more substrates, whereby the multi-layer coating facilitates determination of whether or not a reciprocating element packing needs maintenance.

BRIEF SUMMARY OF THE DRAWINGS

For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts.

FIG. **1** is an elevational view of a reciprocating pump, according to embodiments of this disclosure.

FIG. **2**A is a cut-away illustration of an exemplary reciprocating pump comprising a cross-bore pump fluid end, according to embodiments of the present disclosure.

FIG. **2**B is a cut-away illustration of an exemplary reciprocating pump comprising a cross-bore pump fluid end, according to other embodiments of the present disclosure.

FIG. **3** is a cut-away illustration of an exemplary reciprocating pump comprising a concentric bore pump fluid end, according to embodiments of the present disclosure.

FIG. **4** is cut-away illustration of a pump power end of a pump, according to embodiments of the present disclosure.

FIG. **5** is a cut-away illustration of a pump comprising a packing sleeve and a packing assembly, according to embodiments of the present disclosure.

FIG. **6**A is a schematic of a substrate having a coating disposed thereon, according to embodiments of this disclosure.

FIG. **6**B is a schematic of a substrate having a coating disposed thereon, according to embodiments of this disclosure.

FIG. **7** is a schematic representation of an embodiment of a wellbore servicing system, according to embodiments of this disclosure.

DETAILED DESCRIPTION

It should be understood at the outset that although an illustrative implementation of one or more embodiments are provided below, the disclosed systems and/or methods may be implemented using any number of techniques, whether currently known or in existence. The disclosure should in no way be limited to the illustrative implementations, drawings, and techniques illustrated below, including the exemplary designs and implementations illustrated and described herein, but may be modified within the scope of the appended claims along with their full scope of equivalents.

Disclosed herein is a reciprocating apparatus for pumping pressurized fluid. In embodiments, the reciprocating apparatus comprises a pump fluid end comprising: a cylindrical reciprocating element disposed at least partially within a cylindrical reciprocating element bore and having an outer surface; a reciprocating element packing positioned at a back of the pump fluid end within the reciprocating element bore; and optionally a cylindrical sleeve positioned within the reciprocating element bore such that the reciprocating element reciprocates within the sleeve and having an inner surface proximate the outer surface of the reciprocating element. According to this disclosure, at least a portion of the outer surface of the reciprocating element and/or at least a portion of the inner surface of the sleeve is coated with a multi-layer surface coating comprising a plurality of layers. The plurality of layers include a first layer in contact with the at least a portion of the outer surface of the reciprocating element and/or the at least a portion of the inner surface of the sleeve; and a second layer disposed over at least a portion of the first layer. According to this disclosure, at least one of the plurality of layers has a different visual appearance and/or material composition than at least one other of the plurality of layers. In embodiments, the reciprocating apparatus is a high-pressure pump configured to operate at a pressure greater than or equal to about 3,000 psi and/or in a well servicing operation and environment.

A reciprocating apparatus of this disclosure may comprise any suitable pump operable to pump fluid. Non-limiting examples of suitable pumps include, but are not limited to, piston pumps, plunger pumps, and the like. In embodiments, the pump is a rotary- or reciprocating-type pump such as a positive displacement pump operable to displace pressurized fluid. The pump comprises a pump power end, a pump fluid end, and an integration section whereby a reciprocating element (e.g., a plunger) can be mechanically connected with the pump power end such that the reciprocating element can be reciprocated within a reciprocating element bore of the pump fluid end. FIG. **1** is an elevational view (e.g., side view) of a pump **10** (e.g., a reciprocating pump) according to an exemplary embodiment, the reciprocating pump comprising a pump power end **12**, a pump fluid end **22**, and an integration section **11**. As illustrated in FIG. **1**, pump fluid end has a front S**1** opposite a back S**2** along a first or x-axis, a top S**3** opposite a bottom S**4** along a second or y-axis, wherein the y-axis is in the same plane as and perpendicular to the x-axis, and a left side and a right side along a z-axis, wherein the z-axis is along a plane perpendicular to the plane of the x-axis and the y-axis. Accordingly, toward the top of pump fluid end **22** (and pump **10**) is along the y-axis toward top S**3**, toward the bottom of pump fluid end **22** (and pump **10**) is along the y-axis toward bottom S**4**, toward the front of pump fluid end **22** (and pump **10**) is along the x-axis toward front S**1**, and toward the back of pump fluid end **22** (and pump **10**) is along the x-axis away from front S**1**.

The pump fluid end **22** is integrated with the pump power end **12** via the integration section **11**, such that pump power end **12** is operable to reciprocate the reciprocating element **18** within a reciprocating element bore **24** (FIGS. **2**-**3**) of the pump fluid end **22**. The reciprocating element bore **24** is at least partially defined by a cylinder wall **26**. As described further hereinbelow with reference to FIGS. **2**A-**2**B and FIG. **3**, pump fluid end **22** can be a cross-bore pump fluid end **22** or, alternatively, an in-line or "concentric" bore pump fluid end. As utilized herein, cross-bore pump fluid ends can comprise "T-bore" pump fluid ends, "X-bore" (e.g., cross shaped bore) pump fluid ends, or "Y-bore" pump fluid ends. FIG. **2**A is a schematic showing a cross-bore pump fluid end **22** engaged with a reciprocating element **18**, wherein the cross-bore pump fluid end **22** comprises a cross-bore **25** that makes a cross shape (+) relative to reciprocating element bore **24**. FIG. **2**B is a schematic showing a cross-bore pump fluid end **22** engaged with a reciprocating element **18**, wherein the cross bore pump fluid end **22** comprises a tee-bore **25** that makes a "T" shape relative to reciprocating element bore **24**. FIG. **3** is a schematic showing a concentric bore pump fluid end **22** engaged with a reciprocating element **18**. As discussed further below, the pump **10** includes at least one fluid inlet **38** for receiving fluid from a fluid source, e.g., a suction line, suction header, storage or mix tank, blender, discharge from a boost pump such as a centrifugal pump, etc. The pump **10** also includes at least one discharge outlet **54** for discharging fluid to a discharge source, e.g., a flowmeter, pressure monitoring and control system, distribution header, discharge line, wellhead, discharge manifold pipe, and the like.

The pump **10** may comprise any suitable pump power end **12** for enabling the pump **10** to perform pumping operations (e.g., pumping a wellbore servicing fluid downhole). Similarly, the pump **10** may include any suitable housing **14** for containing and/or supporting the pump power end **12** and components thereof. The housing **14** may comprise various combinations of inlets, outlets, channels, and the like for circulating and/or transferring fluid. Additionally, the housing **14** may include connections to other components and/or systems, such as, but not limited to, pipes, tanks, drive mechanisms, etc. Furthermore, the housing **14** may be configured with cover plates or entryways for permitting access to the pump power end **12** and/or other pump components. As such, the pump **10** may be inspected to determine whether parts need to be repaired or replaced. The pump power end may also be hydraulically driven, whether it is a non-intensifying or an intensifying system.

Those versed in the art will understand that the pump power end **12** may include various components commonly employed in pumps. Pump power end **12** can be any suitable pump known in the art and with the help of this disclosure to be operable to reciprocate reciprocating element **18** in reciprocating element bore **24**. For example, without limitation, pump power end **12** can be operable via and comprise a crank and slider mechanism, a powered hydraulic/pneumatic/steam cylinder mechanism or various electric, mechanical or electro-mechanical drives. FIG. **4** provides a cutaway illustration of an exemplary pump **10** of this disclosure, showing an exemplary pump power end **12**, integrated via integration section **11** with a pump fluid end **22**, wherein the pump power end **12** is operable to reciprocate the reciprocating element **18** within a reciprocating element bore **24** of the pump fluid end **22**. Briefly, for example, the pump power end **12** may include a rotatable crankshaft **16** attached to at least one reciprocating element **18** (e.g., a plunger or piston) by way of a crank arm/connecting rod **20**. Additionally, an engine (e.g., a diesel engine), motor, or other suitable power source may be operatively connected to the crankshaft **16** (e.g., through a transmission and drive shaft) and operable to actuate rotation thereof. In operation, rotation of the crankshaft **16** induces translational movement of the crank arm/connecting rod **20**, thereby causing the reciprocating element **18** to extend and retract along a flow path, which may generally be defined by a central axis **17** within a reciprocating element bore **24** (sometimes referred to herein for brevity as a "reciprocating element bore **24**" or simply a "bore **24**", and wishing to be limited to a particular reciprocating element **18**). Pump **10** of FIG. **1** is typically mounted on a movable structure such as a semi-tractor trailer or skid, and the moveable structure may contain additional components, such as a motor or engine (e.g., a diesel engine), that provides power (e.g., mechanical motion) to the pump power end **12** (e.g., a crankcase comprising crankshaft **16** and related connecting rods **20**).

Of course, numerous other components associated with the pump power end **12** of the pump **10** may be similarly employed, and therefore, fall within the purview of the present disclosure. Furthermore, since the construction and operation of components associated with pumps of the sort depicted in FIG. **1** are well known and understood, discussion of the pump **10** will herein be limited to the extent necessary for enabling a proper understanding of the disclosed embodiments.

As noted hereinabove, the pump **10** comprises a pump fluid end **22** attached to the pump power end **12**. Various embodiments of the pump fluid end **22** are described in detail below in connection with other drawings, for example FIGS. **2**A-**2**B and **3**. Generally, the pump fluid end **22** comprises at least one fluid inlet **38** for receiving fluid, and at least one discharge outlet **54** through which fluid flows out of the discharge chamber **53**. The pump fluid end **22** also comprises at least one valve assembly for controlling the receipt and output of fluid. For example, the pump fluid end **22** can comprise a suction valve assembly **56** and a discharge valve assembly **72**. The pump fluid end **22** may include any suitable component(s) and/or structure(s) for containing and/or supporting the reciprocating element **18** and providing a cylinder wall **26** at least partially defining a reciprocating element bore **24** along which the pump power end can reciprocate the reciprocating element during operation of the pump.

In embodiments, the pump fluid end **22** may comprise a cylinder wall **26** at least partially defining a bore **24** through which the reciprocating element **18** may extend and retract. Additionally, the bore **24** may be in fluid communication with a discharge chamber **53** formed within the pump fluid end **22**. Such a discharge chamber **53**, for example, may be configured as a pressurized discharge chamber **53** having a discharge outlet **54** through which fluid is discharged by the reciprocating element **18**. Thus, the reciprocating element **18** may be movably disposed within the reciprocating element bore **24**, which may provide a fluid flow path into and/or out of the pump chamber. During operation of the pump **10**, the reciprocating element **18** may be configured to reciprocate along a path (e.g., along central axis **17** within bore **24** and/or pump chamber **28**, which corresponds to reciprocal movement parallel to the x-axis of FIG. **1**) to transfer a supply of fluid to the pump chamber **28** and/or discharge fluid from the pump chamber **28**.

In operation, the reciprocating element **18** extends and retracts along a flow path to alternate between providing forward strokes forward strokes (also referred to as discharge strokes and correlating to movement in a positive direction parallel to the x-axis of FIG. **1**, indicated by arrow **117**) and return strokes (also referred to as suction strokes and correlating to movement in a negative direction parallel to the x-axis of FIG. **1**, indicated by arrow **116**), respectively. During a forward stroke, the reciprocating element **18** extends away from the pump power end **12** and toward the pump fluid end **22**. Before the forward stoke begins, the reciprocating element **18** is in a fully retracted position (also referred to as bottom dead center (BDC) with reference to the crankshaft **16**), in which case the suction valve assembly **56** can be in a closed configuration having allowed fluid to flow into the (e.g., high pressure) pump chamber **28**. (As utilized here, "high pressure" indicates possible subjection to high pressure during discharge.) When discharge valve assembly **72** is in a closed configuration (e.g., under the influence of a closing mechanism, such as a spring), the high pressure in a discharge pipe or manifold containing discharge outlet **54** prevents fluid flow into discharge chamber **53** and causes pressure in the pump chamber **28** to accumulate upon stroking of the reciprocating element **18**. When the reciprocating element **18** begins the forward stroke, the pressure builds inside the pump chamber **28** and acts as an opening force that results in positioning of the discharge valve assembly **72** in an open configuration, while a closing force (e.g., via a closing mechanism, such as a spring and/or pressure increase inside pump chamber **28**) urges the suction valve assembly **56** into a closed configuration. When utilized in connection with a valve assembly, 'open' and 'closed' refer, respectively, to a configuration in which fluid can flow through the valve assembly (e.g., can pass between a valve body (e.g., a movable poppet or poppet assembly) and a valve seat thereof) and a configuration in which fluid cannot flow through the valve assembly (e.g., cannot pass between a valve body (e.g., a movable poppet or poppet assembly) and a valve seat thereof). As the reciprocating element **18** extends forward, fluid within the pump chamber **28** is discharged through the discharge outlet **54**.

During a return stroke, the reciprocating element **18** reciprocates or retracts away from the pump fluid end **22** and towards the pump power end **12** of the pump **10**. Before the return stroke begins, the reciprocating element **18** is in a fully extended position (also referred to as top dead center (TDC) with reference to the crankshaft **16**), in which case the discharge valve assembly **72** can be in a closed configuration having allowed fluid to flow out of the pump chamber **28** and the suction valve assembly **56** is in a closed configuration. When the reciprocating element **18** begins and retracts towards the pump power end **12**, the discharge valve assembly **72** assumes a closed configuration, while the suction valve assembly **56** opens. As the reciprocating element **18** moves away from the discharge valve **72** during a return stroke, fluid flows through the suction valve assembly **56** and into the pump chamber **28**.

With reference to the embodiments of FIG. **2**A, which is a schematic showing a cross-bore pump fluid end **22** engaged with a reciprocating element **18**, cross-bore pump fluid end **22** comprises a cross-bore fluid end body **8**, a cross-bore pump chamber **28**, a suction valve assembly **56**, and a discharge valve assembly **72**. In this cross-bore configuration, suction valve assembly **56** and discharge valve assembly **72** are located in a bore or channel **25** (also referred to herein as a cross bore **25**) of pump chamber **28**, wherein bore **25** has a central axis **27** that is parallel to the y-axis of FIG. **1** and is perpendicular to bore **24** in which reciprocating element **18** reciprocates during operation. Suction valve assembly **56** and discharge valve assembly **72** are operable to direct fluid flow within the pump **10**. When reciprocating element **18** retracts, or moves along central axis **17** in a direction away from the pump chamber **28** and the pump fluid end **22** and toward the pump power end **12** (as indicated by arrow **116**), a suction valve of the suction valve assembly **56** opens (e.g., either under natural flow or other biasing means), and a discharge valve of discharge valve assembly **72** will be closed, whereby fluid enters pump chamber **28** via fluid inlet **38**. When the reciprocating element **18** reverses direction, due to the action of the pump power end **12**, the reciprocating element **18** reverses direction along central axis **17**, now moving in a direction toward the pump chamber **28** and pump fluid end **22** and away from pump power end **12** (as indicated by arrow **117**), and the discharge valve of discharge valve assembly **72** is open and the suction valve of suction valve assembly **56** is closed (e.g., again either due to fluid flow and/or other biasing means of valve control), such that fluid is pumped out of pump chamber **28** via discharge outlet **54**.

With reference to the embodiment of FIG. **2**B, which is a schematic showing a T-bore pump fluid end **22** engaged with a reciprocating element **18**, T-bore pump fluid end **22** comprises a T-bore fluid end body **8**, a T-shaped pump chamber **28**, a suction valve assembly **56**, and a discharge valve assembly **72**. In this T-bore configuration of FIG. **2**B, suction valve assembly **56** is coupled with front end **60** of reciprocating element **18** and discharge valve assembly **72** is positioned in bore **25** that makes a tee with reciprocating element bore **24**, i.e., central axis **17** of reciprocating element bore **24** is also the central axis of suction pump assembly **56** and perpendicular to a central axis **27** of discharge valve assembly **72** (i.e., central axis **27** is parallel to the y-axis of FIG. **1** and is perpendicular to bore **24** in which reciprocating element **18** reciprocates during operation). Suction valve assembly **56** and discharge valve assembly **72** are operable to direct fluid flow within the pump **10**. When reciprocating element **18** retracts, or moves along central axis **17** in a direction away from the pump chamber **28** and the pump fluid end **22** and toward the pump power end **12** (as indicated by arrow **116**), a suction valve of the suction valve assembly **56** opens (e.g., either under natural flow or other biasing means), and a discharge valve of discharge valve assembly **72** will be closed, whereby fluid enters pump chamber **28** via fluid inlet **38**. When the reciprocating element **18** reverses direction, due to the action of the pump power end **12**, the reciprocating element **18** reverses direction along central axis **17**, now moving in a direction toward the pump chamber **28** and pump fluid end **22** and away from pump power end **12** (as indicated by arrow **117**), and the discharge valve of discharge valve assembly **72** is open and the suction valve of suction valve assembly **56** is closed (e.g., again either due to fluid flow and/or other biasing means of valve control), such that fluid is pumped out of pump chamber **28** via discharge outlet **54**.

With reference to the embodiment of FIG. **3**, which is a schematic showing a concentric pump fluid end **22** engaged with a reciprocating element **18**, concentric bore pump fluid end **22** comprises a concentric bore fluid end body **8**, a concentric pump chamber **28**, a suction valve assembly **56**, and a discharge valve assembly **72**. In this concentric bore configuration, suction valve assembly **56** and discharge valve assembly **72** are positioned in-line (also referred to as coaxial) with reciprocating element bore **24**, i.e., central axis **17** of reciprocating element bore **24** is also the central axis of suction pump assembly **56** and discharge valve assembly **72**). Suction valve assembly **56** and discharge valve assembly **72** are operable to direct fluid flow within the pump **10**. In some concentric bore fluid end designs, fluid flows within a hollow reciprocating element (e.g., a hollow plunger) **18**. In some such embodiments, the reciprocating element bore **24** of such a concentric bore fluid end design can be defined by a high pressure cylinder **26** providing a high pressure chamber and a low pressure cylinder (not depicted in the embodiment of FIG. **3**) providing a low pressure chamber toward tail end **62** of reciprocating element **18**, whereby fluid from fluid inlet **38** enters reciprocating element **18**. When reciprocating element **18** retracts, or moves along central axis **17** in a direction away from the pump chamber **28** and pump fluid end **22** and toward pump power end **12** (as indicated by arrow **116**), a suction valve of the suction valve assembly **56** opens (e.g., either under natural flow and/or other biasing means), and a discharge valve of discharge valve assembly **72** will be closed, whereby fluid enters pump chamber **28** via a fluid inlet **38**. For a concentric bore pump fluid end **22** design, the fluid inlet can be configured to introduce fluid into pump chamber **28** via a reciprocating element **18** that is hollow and/or via a low pressure chamber as described above. When the reciprocating element **18** reverses direction, due to the action of the pump power end **12**, the reciprocating element **18** reverses direction along central axis **17**, now moving in a direction toward the pump chamber **28** and pump fluid end **22** and away from pump power end **12** (as indicated by arrow **117**), and the discharge valve of discharge valve assembly **72** is open and the suction valve of suction valve assembly **56** is closed (e.g., again either due to fluid flow and/or other biasing means of valve control), such that fluid is pumped out of pump chamber **28** via discharge chamber **53** and discharge outlet **54**.

A pump **10** of this disclosure can comprise one or more access ports. For example, with reference to the cross-bore fluid end body **8** embodiments of FIG. **2**A and FIG. **2**B, a front access port **30**A can be located on a front S**1** of the pump fluid end **22** opposite a back S**2** of the pump fluid end **22**, wherein the back S**2** of the pump fluid end is proximal the pump power end **12**, upon integration therewith via integration section **11**. A top access port **30**B can be located on a top S**3** of the pump fluid end **22** opposite a bottom S**4** of the pump fluid end **22**, wherein the top S**1** of the pump fluid end **22** is above central axis **17** and the bottom S**4** of the pump fluid end **22** is below central axis **17**. With reference to the concentric fluid end body **8** embodiment of FIG. **3**, a front access port **30**A can be located on a front S**1** of the pump fluid end **22** opposite a back S**2** of the pump fluid end **22**, wherein the back S**2** of the pump fluid end is proximal the pump power end **12**, upon integration therewith via integration section **11**. Locations described as front S**1**, back S**2**, top S**3**, and bottom S**4** are further described with reference to the x-y-z coordinate system shown in FIG. **1** and further can be relative to a surface (e.g., a trailer bed, the ground, a platform, etc.) upon which the pump **10** is located, a bottom S**4** of the pump fluid end being proximal the surface (e.g., trailer bed) upon which the pump **10** is located. Generally, due to size and positioning of pump **10**, the front S**1** and top S**3** of the pump fluid end **22** are more easily accessible than a back S**2** or bottom S**4** thereof. In a similar manner, a front of pump **10** is distal the pump power end **12** and a back of the pump **10** is distal the pump fluid end **22**. The integration section **11** can be positioned in a space between the pump fluid end **22** and the pump power end **12**, and can be safeguarded (e.g., from personnel) via a cover **15**.

In embodiments, a pump fluid end **22** and pump **10** of this disclosure comprise at least one access port located on a side of the discharge valve assembly **72** opposite the suction valve assembly **56**. For example, in the cross-bore pump fluid end **22** embodiment of FIG. **2**A, top access port **30**B is located on a side (e.g., top side) of discharge valve assembly **72** opposite suction valve assembly **56**, while in the concentric bore pump fluid end **22** embodiment of FIG. **3**, front access port **30**A is located on a side (e.g., front side) of discharge valve assembly **72** opposite suction valve assembly **56**.

In embodiments, one or more seals **29** (e.g., "o-ring" seals, packing seals, or the like), also referred to herein as 'primary' reciprocating element packing **29** (or simply "packing **29**") may be arranged around the reciprocating element **18** to provide sealing between the outer walls of the reciprocating element **18** and the inner walls **26** defining at least a portion of the reciprocating element bore **24**. The inner walls **26** may be provided by fluid end body **8** or a sleeve **95** within reciprocating element bore **24**, as described below with reference to FIG. **5** and FIGS. **6**A-**6**B. In some concentric bore fluid end designs, a second set of seals (also referred to herein as 'secondary' reciprocating element packing; not shown in the Figures) may be fixedly arranged around the reciprocating element **18** to provide sealing between the outer walls of the reciprocating element **18** and the inner walls of a low-pressure cylinder that defines the low pressure chamber described hereinabove (e.g., wherein the secondary packing is farther back along the x-axis and delineates a back end of the low pressure chamber that extends from the primary packing **29** to the secondary packing). In embodiments, only a primary reciprocating element packing is utilized, as fluid enters tail end **62** of reciprocating element **18** without first contacting an outer peripheral wall thereof (i.e., no secondary reciprocating element packing is needed/utilized, because no low pressure chamber external to reciprocating element **18** is utilized). Skilled artisans will recognize that the seals may comprise any suitable type of seals, and the selection of seals may depend on various factors e.g., fluid, temperature, pressure, etc.

While the foregoing discussion focused on a pump fluid end **22** comprising a single reciprocating element **18** disposed in a single reciprocating element bore **24**, it is to be understood that the pump fluid end **22** may include any suitable number of reciprocating elements. As discussed further below, for example, the pump **10** may comprise a plurality of reciprocating elements **18** and associated reciprocating element bores **24** arranged in parallel and spaced apart along the z-axis of FIG. **1** (or another arrangement such as a V block or radial arrangement). In such a multi-bore pump, each reciprocating element bore may be associated with a respective reciprocating element and crank arm, and a single common crankshaft may drive each of the plurality of reciprocating elements and crank arms. Alternatively, a multi-bore pump may include multiple crankshafts, such that each crankshaft may drive a corresponding reciprocating element. Furthermore, the pump **10** may be implemented as any suitable type of multi-bore pump. In a non-limiting example, the pump **10** may comprise a Triplex pump having three reciprocating elements **18** (e.g., plungers or pistons) and associated reciprocating element bores **24**, discharge valve assemblies **72** and suction valve assemblies **56**, or a Quintuplex pump having five reciprocating elements **18** and five associated reciprocating element bores **24**, discharge valve assemblies **72** and suction valve assemblies **56**.

Reciprocating element bore **24** can have an inner diameter slightly greater than the outer diameter of the reciprocating element **18**, such that the reciprocating element **18** may sufficiently reciprocate within reciprocating element bore **24** (optionally, within a sleeve **95**, as described hereinbelow). In embodiments, the fluid end body **8** of pump fluid end **22** has a pressure rating ranging from about 100 psi to about 3000 psi, or from about 2000 psi to about 10,000 psi, from about 5000 psi to about 30,000 psi, or from about 3000 psi to about 50,000 psi or greater. The fluid end body **8** of pump fluid end **22** may be cast, forged or formed from any suitable materials, e.g., steel, metal alloys, or the like. Those versed in the art will recognize that the type and condition of material(s) suitable for the fluid end body **8** may be selected based on various factors. In a wellbore servicing operation, for example, the selection of a material may depend on flow rates, pressure rates, wellbore service fluid types (e.g., particulate type and/or concentration present in particle laden fluids such as fracturing fluids or drilling fluids, or fluids comprising cryogenic/foams), etc. Moreover, the fluid end body **8** (e.g., cylinder wall **26** defining at least a portion of reciprocating element bore **24** and/or pump chamber **28**) may include protective coatings for preventing and/or resisting abrasion, erosion, and/or corrosion.

In embodiments, the cylindrical shape (e.g., providing cylindrical wall(s) **26**) of the fluid end body **8** may be pre-stressed in an initial compression. Moreover, a high-pressure cylinder(s) providing the cylindrical shape (e.g., providing cylindrical wall(s) **26**) may comprise one or more sleeves (e.g., heat-shrinkable sleeves). Additionally or alternatively, the high-pressure cylinder(s) may comprise one or more composite overwraps and/or concentric sleeves ("over-sleeves"), such that an outer wrap/sleeve pre-loads an inner wrap/sleeve. The overwraps and/or over-sleeves may be non-metallic (e.g., fiber windings) and/or constructed from relatively lightweight materials. Overwraps and/or over-sleeves may be added to increase fatigue strength and overall reinforcement of the components.

The cylinders and cylindrical-shaped components (e.g., providing cylindrical wall **26**) associated with the pump fluid end body **8** of pump fluid end **22** may be held in place within the pump **10** using any appropriate technique. For example, components may be assembled and connected, e.g., bolted, welded, etc. Additionally or alternatively, cylinders may be press-fit (e.g., interference fit) into openings machined or cast into the pump fluid end **22** or other suitable portion of the pump **10**. Such openings may be configured to accept and rigidly hold cylinders (e.g., having cylinder wall(s) **26** at least partially defining reciprocating element bore **24**) in place so as to facilitate interaction of the reciprocating element **18** and other components associated with the pump **10**.

With reference to FIG. **5**, which is a cut-away illustration of a pump **10**, cylinder wall **26** can be provided by a cylindrical packing sleeve **95**, in embodiments. Sleeve **95** can be press fit (e.g., interference fit) into reciprocating element bore **24**, in embodiments. Sleeve **95** can have an inner surface **95**A about an inside diameter thereof and proximate reciprocating element **18**.

With reference to FIG. **5**, in embodiments, a packing assembly **90** comprising packing **29** is positioned within sleeve **95**. In embodiments, pump fluid end **22** comprises a packing assembly **90**, such that packing **29**, a packing carrier **91**, and a packing screw **92** can be removed from back S2 of pump fluid end **22** when crankshaft **16** is at TDC, as described, for example, in U.S. patent application Ser. No. 16/411,911 filed May 14, 2019, which is entitled "Pump Fluid End with Positional Indifference for Maintenance", the disclosure of which is hereby incorporated herein in its entirety for purposes not contrary to this disclosure.

FIG. **6** is a cut-away illustration of a pump **10** comprising a packing assembly **90** in pump fluid end **22**, with a crankshaft **16** (FIG. **4**) at top dead center (TDC), according to embodiments of the present disclosure. Packing assembly **90** comprises a packing screw **92**, a packing carrier **91**, and a packing **29**. Packing screw **92**, packing carrier **91**, and packing **29** are cylindrical and have a width measured an axial distance along a central axis thereof (i.e., central axis **17**, when assembled in pump fluid end **22**) that is less than the minimum spacing distance D1 of pump **10** comprising the pump fluid end **22** and a pump power end **12**. When packing assembly **90** is assembled in pump fluid end **22**, the central axis of packing screw **92**, the central axis of packing carrier **91**, and the central axis of packing **29** are coincident (also referred to as coaxial) with central axis **17** of reciprocating element bore **24**.

As described hereinabove with reference to FIGS. **1-4**, pump fluid end **22** comprises a reciprocating element bore **24** in which a reciprocating element **18** can be reciprocated via the pump power end **12** via connection of a tail end **62** of the reciprocating element **18** to a pushrod **30** and crankshaft **16** of the pump power end **12**, via one or more mechanical linkages **4**. In the embodiment of FIG. **6**, the front **4**A of the one or more mechanical linkages **4** (FIG. **4**) is positioned a minimum spacing distance D**1** that is an axial distance measured along the central axis **17** between back S2 of the pump fluid end **22** and a front end **4**A of the mechanical linkages **4** component closest to pump fluid end **22** when the crankshaft **16** of the pump power end **22** is at top dead center (TDC). The component of mechanical linkages **4** closest to pump fluid end **22** when crankshaft **16** of pump power end **12** is at TDC can comprise, for example, an adapter configured to couple reciprocating element **18** with a pushrod **30** of pump power end **12**. When assembled, packing assembly **90** can be positioned generally where packing **29** is depicted in FIG. 2A, FIG. 2B, and FIG. **3**.

Packing screw **92** can be designed such that, once packing **29** and packing carrier **91** are inserted into reciprocating element bore **24** of pump fluid end **22**, packing screw **92** can be inserted into reciprocating element bore **24** and coupled (e.g., threaded together) with pump fluid body **8** of pump fluid end **22**, such that packing screw **92** retains packing carrier **91** and packing screw **29** in pump fluid end **22** during pump operation.

In the embodiment of FIG. **6**, pump **10** comprises cylindrical sleeve **95** (as described hereinabove) within reciprocating element bore **24**. Packing **29**, packing carrier **91**, packing screw **92**, or a combination thereof can be located within such a sleeve **95** toward the back S2 of the pump fluid end **22**. In some such embodiments, pump fluid end **22** is a concentric bore pump fluid end **22**, such as described hereinabove with reference to the embodiment of FIG. **3**. Alternatively, packing **29**, packing carrier **91**, packing screw **92**, or a combination thereof can be located within reciprocating element bore **24** toward the back S2 of the pump fluid end **22**, the reciprocating element bore **24** containing no sleeve **95**. In some such embodiments, pump fluid end **22** is a cross-bore pump fluid end **22**, such as described hereinabove with reference to the embodiment of FIG. **2**A-**2**B.

With respect to a front side and a back side of packing **29**, packing carrier **91**, and packing screw **92**, the front side is axially distal the pump power end **12** (i.e., is farther along central axis **17** from pump power end **12**) relative to the back side thereof, which is axially proximate pump power end **12** (i.e., is closer along central axis **17** to pump power end **12** than the front side). Upon assembly within pump fluid end **22**, a front side **29**A of packing **29** is distal pump power end **12**, a back side **29**B of the packing **29** axially proximate the pump power end **12** contacts a front side **91**A of the packing carrier **91** axially distal the pump power end **21**, and at least a portion of a front side **92**A of the packing screw axially distal the pump power end **12** contacts a back side **91**B of the packing carrier **91** axially proximate the pump power end **12**.

In embodiments, packing screw **92** comprises threads on at least a portion of an outside diameter thereof, or other features, whereby the packing screw **92** can be threadably, or otherwise, connected with a mating thread on a portion **24**A of an inside diameter of the reciprocating element bore **24** (and/or sleeve **95** therein), such that, upon assembly within pump fluid end **22**, the packing screw **92** retains the packing **29** and the packing carrier **91** in the pump fluid end **22**.

In embodiments, when assembled into packing assembly **90**, packing **29** is positioned within the reciprocating element bore **24** and/or sleeve **95** therein toward the back S2 of the pump fluid end **22** such that front side **29**A of packing **29** is in contact with a shoulder or stop feature **3** associated with reciprocating element bore **24** and/or sleeve **95**. When assembled into packing assembly **90**, packing carrier **91** is positioned such that front side **91**A of the packing carrier **91** distal pump power end **12** is in contact with back side **29**B of the packing **29** proximate the pump power end. When assembled into packing assembly **90**, the packing screw **92** is positioned such that at least a portion of front side **92**A of the packing screw **92** is in contact with back side **91**B of the packing carrier **91** proximate the pump power end **12** and the packing screw **92** is coupled (e.g., threaded) with an inside surface of the reciprocating element bore **24** and/or packing sleeve **95**. Once assembled, the packing screw **92** thus retains the packing carrier **91** and the packing **29** within the pump fluid end **22**.

In embodiments, the reciprocating element **18** comprises a plunger or a piston. While the reciprocating element **18** may be described herein with respect to embodiments comprising a plunger, it is to be understood that the reciprocating element **18** may comprise any suitable component for displacing fluid. In a non-limiting example, the reciprocating element **18** may be a piston. As those versed in the art will readily appreciate, a piston-type pump generally employs sealing elements (e.g., rings, packing, etc.) attached to the piston and movable therewith. In contrast, a plunger-type pump generally employs fixed or static seals (e.g., primary seal or packing **29**) through which the plunger moves during each stroke (e.g., suction stroke or discharge stroke).

As skilled artisans will understand, the reciprocating element **18** may include any suitable size and/or shape for extending and retracting along a flow path within the pump fluid end **22**. For instance, reciprocating element **18** may comprise a generally cylindrical shape, and may be sized such that the reciprocating element **18** can sufficiently slide against or otherwise interact with the inner cylinder wall **26** (e.g., provided by pump fluid end body **8** and/or sleeve **95**). Reciprocating element **18** has an outer surface **18**A about an outside diameter thereof. In embodiments, one or more additional components or mechanical linkages **4** (FIG. **4**; e.g., clamps, adapters, extensions, etc.) may be used to couple the reciprocating element **18** to the pump power end **12** (e.g., to a pushrod **30**).

In some embodiments (e.g., cross-bore pump fluid end **22** embodiments such as FIG. **2**A), the reciprocating element may be substantially solid and/or impermeable (e.g., not hollow). In alternative embodiments (e.g., tee-bore pump fluid end **22** embodiment such as FIG. **2**B and concentric bore pump fluid end **22** embodiment such as FIG. **3**), the reciprocating element **18** comprises a peripheral wall defining a hollow body. Additionally (e.g., tee-bore pump fluid end **22** embodiments such as FIG. **2**B and concentric bore pump fluid end **22** embodiments such as FIG. **3**), a portion of the peripheral wall of reciprocating element **18** may be generally permeable or may include an input through which fluid may enter the hollow body and an output through which fluid may exit the hollow body. Furthermore, while the reciprocating element **18** may, in embodiments, define a substantially hollow interior and include a ported body, a base of the reciprocating element **18** proximal the pump power end **12**, when assembled, may be substantially solid and/or impermeable (e.g., a plunger having both a hollow portion and a solid portion).

The reciprocating element **18** comprises a front or free end **60**. In embodiments comprising concentric bore pump fluid end designs **22** such as shown in FIG. **3**, the reciprocating element **18** can contain or at least partially contain the suction valve assembly **56**. In one aspect, the suction valve assembly **56** is at least partially disposed within the reciprocating element **18** at or proximate to the front end **60** thereof. At an opposite or tail end **62** (also referred to as back end **62**) of the reciprocating element **18**, the reciprocating element **18** may include a base coupled to the pump power end **12** of the pump **10** (e.g., via crank arm **20**). In embodiments, the tail end **62** of the reciprocating element **18** is coupled to the pump power end **12** outside of pump fluid end **22**, e.g., within integration section **11**.

As noted above, pump fluid end **22** contains a suction valve assembly **56**. Suction valve assembly **56** may alternately open or close to permit or prevent fluid flow. Skilled artisans will understand that the suction valve assembly **56** may be of any suitable type or configuration (e.g., gravity- or spring-biased, flow activated, etc.). Those versed in the art will understand that the suction valve assembly **56** may be disposed within the pump fluid end **22** at any suitable location therein. For instance, the suction valve assembly **56** may be disposed within the bore **25** below central axis **17** of the pump fluid end **22**, in cross-bore pump fluid end **22** designs such as FIG. **2**A, such that a suction valve body (e.g., a poppet) of the suction valve assembly **56** moves away from a suction valve seat within the a suction valve seat housing of reciprocating element **18** when the suction valve assembly **56** is in an open configuration and toward the suction valve seat when the suction valve assembly **56** is in a closed configuration. The suction valve assembly **56** may be disposed within reciprocating element bore **24** and at least partially within reciprocating element **18** in tee-bore pump fluid end **22** designs such as FIG. **2**B and concentric bore pump fluid end **22** designs such as FIG. **3**, such that a suction valve body (e.g., a poppet) of the suction valve assembly **56** moves away from a suction valve seat within and/or coupled with a suction valve seat housing of reciprocating element **18** when the suction valve assembly **56** approaches an open configuration (i.e., is opening) and toward the suction valve seat when the suction valve assembly **56** approaches a closed configuration (e.g., is closing).

Pump **10** comprises a discharge valve assembly **72** for controlling the output of fluid through discharge chamber **53** and discharge outlet **54**. Analogous to the suction valve assembly **56**, the discharge valve assembly **72** may alternately open or close to permit or prevent fluid flow. Those versed in the art will understand that the discharge valve assembly **72** may be disposed within the pump chamber at any suitable location therein. For instance, the discharge valve assembly **72** may be disposed within the bore **25** proximal the top S**3** of the pump fluid end **22**, in cross-bore pump fluid end **22** designs such as FIG. **2**A and tee-bore pump fluid end **22** designs such as FIG. **2**B, such that a discharge valve body (e.g., a poppet) of the discharge valve assembly **72** moves toward the discharge chamber **53** when the discharge valve assembly **72** approaches an open configuration and away from the discharge chamber **53** when the discharge valve assembly **72** approaches a closed configuration. The discharge valve assembly **72** may be disposed proximal the front S**1** of bore **24** of the pump fluid end **22** (e.g., at least partially within discharge chamber **53** and/or pump chamber **28**) in concentric bore pump fluid end **22** designs such as FIG. **3**, such that a discharge valve body (e.g., a poppet) of the discharge valve assembly **72** moves toward the discharge chamber **53** when the discharge valve assembly **72** approaches an open configuration and away from the discharge chamber **53** when the discharge valve assembly **72** approaches a closed configuration. In addition, the discharge valve assembly **72** may be co-axially aligned with the suction valve assembly **56** (e.g., along central axis **17** in concentric bore pump fluid end **22** configurations such as FIG. **3** or along central axis **27** of bore **25** perpendicular to central axis **17** in cross-bore pump fluid end **22** configurations such as FIG. **2**A and FIG. **2**B). In concentric bore pump fluid end **22** configurations such as FIG. **3**, the suction valve assembly **56** and the discharge valve assembly **72** may be coaxially aligned with the reciprocating element **18** (e.g., along central axis **17**).

Further, the suction valve assembly **56** and the discharge valve assembly **72** can comprise any suitable mechanism for opening and closing valves. For example, the suction valve assembly **56** and the discharge valve assembly **72** can comprise a suction valve spring and a discharge valve spring, respectively. Additionally, any suitable structure (e.g., valve assembly comprising sealing rings, stems, poppets, valve guides, etc.) and/or components may be employed for retaining the components of the suction valve assembly **56** and the components of the discharge valve assembly **72** within the pump fluid end **22**.

The fluid inlet **38** may be arranged within any suitable portion of the pump fluid end **22** and configured to supply fluid to the pump in any direction and/or angle. Moreover, the pump fluid end **22** may comprise and/or be coupled to any suitable conduit (e.g., pipe, tubing, or the like) through which a fluid source may supply fluid to the fluid inlet **38**. The pump **10** may comprise and/or be coupled to any suitable fluid source for supplying fluid to the pump via the fluid inlet **38**. In embodiments, the pump **10** may also comprise and/or be coupled to a pressure source such as a boost pump (e.g., a suction boost pump) fluidly connected to the pump **10** (e.g., via inlet **38**) and operable to increase or "boost" the pressure of fluid introduced to pump **10** via fluid inlet **38**. A boost pump may comprise any suitable type including, but not limited to, a centrifugal pump, a gear pump, a screw pump, a roller pump, a scroll pump, a piston/plunger pump, or any combination thereof. For instance, the pump **10** may comprise and/or be coupled to a boost pump known to operate efficiently in high-volume operations and/or may allow the pumping rate therefrom to be adjusted. Skilled artisans will readily appreciate that the amount of added pressure may depend and/or vary based on factors such as operating conditions, application requirements, etc. In one aspect, the boost pump may have an outlet pressure greater than or equal to about 70 psi, about 80 psi, or about 110 psi, providing fluid to the suction side of pump **10** at about said pressures. Additionally or alternatively, the boost pump may have a flow rate of greater than or equal to about 80 BPM, about 70 BPM, and/or about 50 BPM.

As noted hereinabove, the pump **10** may be implemented as a multi-cylinder pump comprising multiple cylindrical reciprocating element bores **24** and corresponding components. In embodiments, the pump **10** is a Triplex pump in which the pump fluid end **22** comprises three reciprocating assemblies, each reciprocating assembly comprising a suction valve assembly **56**, a discharge valve assembly **72**, a pump chamber **28**, a fluid inlet **38**, a discharge outlet **54**, and a reciprocating element bore **24** within which a corresponding reciprocating element **18** reciprocates during operation of the pump **10** via connection therewith to a (e.g., common) pump power end **12**. In embodiments, the pump **10** is a Quintuplex pump in which the pump fluid end **22** comprises five reciprocating assemblies. In a non-limiting example, the pump **10** may be a Q10™ Quintuplex Pump or an HT-400™ Triplex Pump, produced by Halliburton Energy Services, Inc.

In embodiments, the pump fluid end **22** may comprise an external manifold (e.g., a suction header) for feeding fluid to the multiple reciprocating assemblies via any suitable inlet(s). Additionally or alternatively, the pump fluid end **22** may comprise separate conduits such as hoses fluidly connected to separate inlets for inputting fluid to each reciprocating assembly. Of course, numerous other variations may be similarly employed, and therefore, fall within the scope of the present disclosure.

Those skilled in the art will understand that the reciprocating elements of each of the reciprocating assemblies may be operatively connected to the pump power end **12** of the pump **10** according to any suitable manner. For instance, separate connectors (e.g., cranks arms/connecting rods **20**, one or more additional components or mechanical linkages **4**, pushrods **30**, etc.) associated with the pump power end **12** may be coupled to each reciprocating element body or tail end **62**. The pump **10** may employ a common crankshaft (e.g., crankshaft **16**) or separate crankshafts to drive the multiple reciprocating elements.

As previously discussed, the multiple reciprocating elements may receive a supply of fluid from any suitable fluid source, which may be configured to provide a constant fluid supply. Additionally or alternatively, the pressure of supplied fluid may be increased by adding pressure (e.g., boost pressure) as described previously. In embodiments, the fluid inlet(s) **38** receive a supply of pressurized fluid comprising a pressure ranging from about 30 psi to about 300 psi.

Additionally or alternatively, the one or more discharge outlet(s) **54** may be fluidly connected to a common collection point such as a sump or distribution manifold, which may be configured to collect fluids flowing out of the fluid outlet(s) **54**, or another cylinder bank and/or one or more additional pumps.

During pumping, the multiple reciprocating elements **18** will perform forward and returns strokes similarly, as described hereinabove. In embodiments, the multiple reciprocating elements **18** can be angularly offset to ensure that no two reciprocating elements are located at the same position along their respective stroke paths (i.e., the plungers are "out of phase"). For example, the reciprocating elements may be angularly distributed to have a certain offset (e.g., 120 degrees of separation in a Triplex pump) to minimize undesirable effects that may result from multiple reciprocating elements of a single pump simultaneously producing pressure pulses. The position of a reciprocating element is generally based on the number of degrees a pump crankshaft (e.g., crankshaft **16**) has rotated from a bottom dead center (BDC) position. The BDC position corresponds to the position of a fully retracted reciprocating element at zero velocity, e.g., just prior to a reciprocating element moving (i.e., in a direction indicated by arrow **117** in FIGS. **2**A-**2**B and FIG. **3**) forward in its cylinder. A top dead center position corresponds to the position of a fully extended reciprocating element at zero velocity, e.g., just prior to a reciprocating element moving backward (i.e., in a direction indicated by arrow **116** in FIGS. **2**A-**2**B and FIG. **3**) in its cylinder.

As described above, each reciprocating element **18** is operable to draw in fluid during a suction (backward or return) stroke and discharge fluid during a discharge (forward) stroke. Skilled artisans will understand that the multiple reciprocating elements **18** may be angularly offset or phase-shifted to improve fluid intake for each reciprocating element **18**. For instance, a phase degree offset (at 360 degrees divided by the number of reciprocating elements) may be employed to ensure the multiple reciprocating elements **18** receive fluid and/or a certain quantity of fluid at all times of operation. In one implementation, the three reciprocating elements **18** of a Triplex pump may be phase-shifted by a 120-degree offset. Accordingly, when one reciprocating element **18** is at its maximum forward stroke position, a second reciprocating element **18** will be 60 degrees through its discharge stroke from BDC, and a third reciprocating element will be 120 degrees through its suction stroke from top dead center (TDC).

Herein disclosed are a multi-layer coating for a substrate, a substrate having disposed thereon the multi-layer coating, a pump fluid end **22** comprising such a coated substrate, and a pump comprising such a pump fluid end **22**. FIG. **6**A is a schematic of a substrate **50** having a coating **70** disposed thereon to provide a coated substrate **55**, according to embodiments of this disclosure. FIG. **6**B is a schematic of a substrate **50** having a coating **70** disposed thereon to provide a coated substrate **55**, according to other embodiments of this disclosure. Substrate **50** has coating contact surface **50**A to which a first layer L**1** of multi-layer coating **70** is directly applied. At least a second layer L**2** is disposed over at least a portion of first layer L**1**. At least one of the plurality of layers L has a different visual appearance and/or material composition than at least one other of the plurality of layers L.

In embodiments, as depicted in the embodiment of FIG. **6**A, the multilayer surface coating **70** consists of the first layer L**1** and the second layer L**2**, and the first layer L**1** has a different visual appearance and/or material composition than the second layer L**2**. In embodiments, a color of the second layer L**2** is different from a color of the first layer L**1**. For example, and without limitation, in embodiments, the color of the first layer L**1** can be yellow. In embodiments, the color or the second layer L**2** is black, grey, brown, blue, or white.

In embodiments, the multilayer surface coating **70** further comprises at least one additional layer disposed on the second layer. For example, as depicted in the embodiment of FIG. **6**B, in embodiments, the multi-layer coating **70** comprises a third layer L**3** disposed over at least a portion of the second layer L**2** and/or a fourth layer L**4** disposed over at least a portion of the third layer L**3**.

In embodiments, each layer of the plurality of layers L has an average thickness T_L in a range of from about 0.01 to about 0.04 inch (from about 254 to about 1016 μm), from about 0.01 to about 0.03 inch (from about 254 to about 762 μm), from about 0.01 to about 0.02 inch (from about 254 to about 508 μm), or less than or equal to about 0.04 inch (1016 μm), 0.03 inch (762 μm), 0.02 inch (508 μm), or 0.01 inch (254 μm). In embodiments, an average thickness T**1** of the first layer L**1**, an average thickness T**2** of the second layer L**2**, an average thickness T**3** of the third layer L**3**, and/or an average thickness T**4** of the fourth layer L**4** is in a range of from about 0.01 to about 0.04 inch (from about 254 to about 1016 μm), from about 0.01 to about 0.03 inch (from about 254 to about 762 μm), from about 0.01 to about 0.02 inch (from about 254 to about 508 μm), or less than or equal to about 0.04 inch (1016 μm), 0.03 inch (762 μm), 0.02 inch (508 μm), or 0.01 inch (254 μm). In embodiments, a thickness of the first layer L**1** is less uniform along a central axis of cylindrical substrate **50** than a thickness of the remaining layer(s).

In embodiments, a the multilayer surface coating **70** has an average thickness T_C equal to the sum of the average thicknesses of each layer of the plurality of layers L of the coating **70** that is in a range of from about 0.01 to about 0.04 inch (from about 254 to about 1016 μm), from about 0.01 to about 0.03 inch (from about 254 to about 762 μm), from about 0.01 to about 0.02 inch (from about 254 to about 508 μm), or less than or equal to about 0.04 inch (1016 μm), 0.03 inch (762 μm), 0.02 inch (508 μm), or 0.01 inch (254 μm). For example, in embodiments such as depicted in FIG. **6**A, an average thickness T_C of multi-layer surface coating **70** of FIG. **6**A is equivalent to the sum of the average thickness T**1** of first layer L**1** and the average thickness T**2** of second coating L**2**. Such an average thickness T_C of multi-layer surface coating **70** can be in a range of from about 0.01 to about 0.04 inch (from about 254 to about 1016 μm), from about 0.01 to about 0.03 inch (from about 254 to about 762 μm), from about 0.01 to about 0.02 inch (from about 254 to about 508 μm), or less than or equal to about 0.04 inch (1016 μm), 0.03 inch (762 μm), 0.02 inch (508 μm), or 0.01 inch (254 μm). In embodiments such as depicted in FIG. **6**B, an average thickness T_C of multi-layer surface coating **70** is equivalent to the sum of the average thickness T**1** of first layer L**1**, the average thickness T**2** of second coating L**2**, the average thickness T**3** of third layer L**3**, and the average thickness T**4** of fourth layer L**4**. Such an average thickness T_C of multi-layer surface coating **70** of FIG. **6**B can be in a range of from about 0.01 to about 0.04 inch (from about 254 to about 1016 μm), from about 0.01 to about 0.03 inch (from about 254 to about 762 μm), from about 0.01 to about 0.02 inch (from about 254 to about 508 μm), or less than or equal to about 0.04 inch (1016 μm), 0.03 inch (762 μm), 0.02 inch (508 μm), or 0.01 inch (254 μm).

In embodiments, at least one layer (e.g., first layer L**1**) of multi-layer coating **70** comprises a nickel-based spray layer, iron particles, an aluminum bronze layer, or a combination thereof. In embodiments, at least one other layer (e.g., second layer L2) of multi-layer coating 70 comprises titanium, ceramic alumina, a nickel-based spray, iron particles, or a combination thereof that is different from the at least one layer (e.g., the first layer L1).

In embodiments, at least one layer L of the plurality of layers (e.g., the first layer L1 and/or the second layer L2) of multi-layer coating 70 independently comprises a high velocity oxygen fuel (HVOF) layer, a combustion flame spray layer, a plasma spray layer, a vacuum plasma spray layer, a two wire electric arc spray layer, or a combination thereof. In embodiments, each layer of the plurality of layers L of multi-layer coating 70 independently comprises a nickel-based spray layer (e.g., COLMONOY®, available from WallColmonoy) that can have a grey color, a titanium nitride layer (e.g., a PVD coating) that can have a gold color, a ceramic alumina layer (e.g., a plasma spray layer) that can have a white color, an alumina bronze layer that can have a yellow color, or a combination thereof. In embodiments, an alumina bronze layer, having a yellow color which may be particularly suitable for use as a bond coat layer, is utilized as first layer L1 that directly contacts contact surface 50A of substrate 50.

By way of specific, non-limiting examples, an under bond layer (e.g., a first layer L1) of nickel based spray (e.g., COLMONOY), which has a grey color, can be utilized with an outer layer (e.g., a second layer L2) of titanium (e.g., physical vapor deposition (PVD) coating) having a gold color. Alternatively, an under bond layer (e.g., a first layer L1) of nickel based spray (e.g., COLMONOY), which has a grey color, can be utilized with an outer layer (e.g., a second layer L2) of ceramic alumina (e.g., a plasma spray) having a white color. Alternatively, an under bond layer (e.g., a first layer L1) of aluminum bronze, which has a yellow color can be utilized with an outer layer (e.g., a second layer L2) of nickel based spray (e.g., COLMONOY), having a grey color.

In embodiments, multi-layer coating 70 consists of a first layer L1 of alumina bronze that is yellow in color, and a second layer L2 of nickel based spray (e.g., COLMONOY), that is grey in color. In specific, non-limiting embodiments, the first layer L1 has a thickness T1 of about 0.020 inch (508 μm) and the second layer L2 has a thickness T2 of about 0.01 inch (254 μm).

In embodiments, the substrate 50 upon which multi-layer coating 70 is disposed includes reciprocating element 18, in which case the coating contact surface 50A comprises outer surface 18A of reciprocating element 18 (FIGS. 2A-2B and FIG. 3) prior to coating thereof with multi-layer coating 70. In embodiments, a coated reciprocating element 18 (e.g., a reciprocating element 18 coated with a multi-layer surface coating 70 of this disclosure) can be utilized to provide a wear level determination of the reciprocating element packing 29 and/or of the coated reciprocating element 18. As noted hereinabove, the reciprocating element 18 can be a plunger, wherein packing 29 does not reciprocate along with reciprocation of the plunger. In embodiments, reciprocating element 18 comprises a piston comprising one or seals (e.g., sealing rings) disposed about an outer circumference thereof, wherein the one or more seals reciprocate with the piston. In embodiments in which reciprocating element 18 is a piston, optional sleeve 95 can comprise a piston liner.

In embodiments, the substrate 50 upon which multi-layer surface coating 70 is disposed includes sleeve 95, in which case the coating contact surface 50A comprises inner surface 95A (FIG. 5) prior to coating thereof with multi-layer surface coating 70. In embodiments, a coated sleeve 95 (e.g., a sleeve 95 coated with a multi-layer surface coating 70 of this disclosure) can be utilized to provide a wear level determination of the packing 29 and/or of the coated sleeve 95. In embodiments, at least a portion of the outer surface 18A of the reciprocating element comprises a multilayer surface coating 70 of this disclosure and at least a portion of the inner surface 95A of the sleeve 95 comprises a multilayer surface coating 70 of this disclosure, which can be the same as or different from the coating of the at least a portion of the outer surface 18A of the reciprocating element 18. Coating both the reciprocating element and the sleeve can be utilized to provide a redundancy in the wear level determination of the packing 29, while also providing a wear level indication of the coated reciprocating element 18 and the coated sleeve 95, respectively.

Sleeve 95 can be a replaceable sleeve 95, an insert sleeve 95, and/or a stuffing box 95 that houses reciprocating element packing 29. The life of reciprocating element packing 29 can be affected by the condition of sleeve 95 and/or reciprocating element 18. Dimensional wear, scratches, and/or pitting of sleeve 95 and/or reciprocating element 18 can detrimentally affect the life of reciprocating element packing 29. Accordingly, the use of a multi-layer surface coating 70 on sleeve 95 and/or reciprocating element 18, such that wear of sleeve 95 and/or reciprocating element 18 can be determined by examination of the inner surface 95A or the outer surface, 18A respectively, thereof as described hereinbelow, can result in repair and/or replacement of sleeve 95 and/or reciprocating element 18 prior to unacceptable wear on reciprocating element packing 29, in embodiments. The wear on a coated sleeve 95 and/or a coated reciprocating element 18 can also be utilized to determine the wear level of reciprocating element packing 29 and/or be utilized to determine when reciprocating element packing 29 will be (or is) in need of repair and/or replacement.

In embodiments, reciprocating element 18 comprises tool engagement features on front 60 thereof, whereby reciprocating element 18 can be removed from pump fluid end 22 by engaging a tool with the engagement features, as described, for example, in U.S. patent application Ser. No. 16/411,905 filed May 14, 2019, which is entitled "Pump Plunger with Wrench Features", the disclosure of which is hereby incorporated herein in its entirety for purposes not contrary to this disclosure.

In embodiments, reciprocating element 18 is coupled with a pushrod 30 (or another component of mechanical linkages 4 (FIG. 4)) of pump power end 12 via a reciprocating element adapter, as described, for example, in U.S. patent application Ser. No. 16/411,894 filed May 14, 2019, which is entitled "Easy Change Pump Plunger", the disclosure of which is hereby incorporated herein in its entirety for purposes not contrary to this disclosure.

Also disclosed herein is a pump fluid end comprising a coated substrate 55, as described hereinabove. Such a pump fluid end 22 comprising substrate 50 having disposed thereon multi-layer coating 70 to provide coated substrate 55 comprises: a cylindrical reciprocating element 18 disposed at least partially within a cylindrical reciprocating element bore 24 and having an outer surface 18A; a reciprocating element packing 29 positioned at a back S2 (FIG. 1, FIG. 2A-2B, FIG. 3, FIG. 5) of the pump fluid end 22 within the reciprocating element bore 24; and optionally a cylindrical sleeve 95 (FIG. 5) positioned within the reciprocating element bore 24 such that the reciprocating element 18 reciprocates within the sleeve 95 and having an inner surface 95A proximate the outer surface 18A of the reciprocating element 18. According to this disclosure, at least a portion of the outer surface 18A of the reciprocating element 18 and/or at least a portion of the inner surface **95**A of the sleeve **95** comprises multi-layer surface coating **70** comprising a plurality of layers L. The plurality of layers L include: a first layer L**1** in contact with the at least a portion of the outer surface **18**A of the reciprocating element **18** and/or the at least a portion of the inner surface **95**A of the sleeve **95**; and a second layer L**2** disposed over at least a portion of the first layer L**1**. According to this disclosure, at least one of the plurality of layers L has a different visual appearance and/or material composition than at least one other of the plurality of layers L. For example, when the multilayer surface coating **70** consists of the first layer L**1** and the second layer L**2**, the first layer L**1** has a different visual appearance (e.g., yellow color) and/or material composition than the second layer L**2**.

In embodiments, the different visual appearance comprises a different color (e.g., a L**1** of the coating having a yellow color that becomes visible as all or a portion of L**2** of the coating degrades or is otherwise removed). In embodiments, a different material composition comprises the presence of a magnetic material, such as iron particles. In embodiments, the difference in material composition can be determined by ultrasonic inspection, magnetic field detection, eddy current, liquid penetrant, visual inspection (e.g., color change(s)), or a combination thereof.

In embodiments, the multi-layer surface coating on the reciprocating element **18** is utilized to determine a wear level of the reciprocating element **18**. In embodiments, the multi-layer surface coating on the sleeve **95** is utilized to determine a wear level of the sleeve **95**. In embodiments, the multi-layer surface coating on the reciprocating element **18** and/or the sleeve **95** is utilized to determine a wear level of packing **29**. In such embodiments, the visual appearance and/or material composition of each layer of the plurality of layers L can indicate a condition (e.g., a specific wear level) of the coated substrate **55** (e.g., of the coated reciprocating element **18** and/or of the coated sleeve **95**) and/or of the packing **29**. For example, in embodiments, the multi-layer surface coating **70** consists of first layer L**1** and second layer L**2**, and an initial thickness $T2_i$ of the second layer L**2** is equal to a maximum wear allowance of the coated substrate **55** and/or of the packing **29**. Accordingly, if examination (e.g., visual examination, and/or other examination to determine a thickness and/or material composition of the exposed layer of multi-layer coating **70**) of the coated substrate **55** (e.g., the coated reciprocating element **18** and/or the coated sleeve **95**) reveals that first layer L**1** is exposed (i.e., second layer L**2** has been completely worn away at one or more positions along central axis **17**A), the coated substrate and/or the packing **29** can be deemed to have worn a maximum level and can be determined to be in need of repair and/or replacement (i.e., repacking of reciprocating element packing **29** and/or replacement or recoating of the coated substrate (e.g., the coated reciprocating element **18** and/or the coated sleeve **95**) is needed).

In embodiments, each layer of the plurality of layers L of multi-layer surface coating **70** indicates a specific wear level of the coated substrate **55** and/or of the packing **29**. For example, with reference now to the embodiment of FIG. **6**B, fourth layer L**4** can indicate a first condition (or Condition A) of wear, third layer L**3** can indicate a second condition (or Condition B) of wear, second layer L**2** can indicate a third condition (or Condition C) of wear, and first layer L**1** can indicate a fourth condition (or Condition D) of wear of reciprocating element **29** and/or of the coated substrate **55**. For example, with reference to the embodiment of FIG. **6**B, fourth layer L**4** can indicate a "not worn" wear level of packing **29** and/or coated substrate **55**, third layer L**3** of multi-layer surface coating **70** can indicate a "slightly worn" wear level of packing **29** and/or coated substrate **55**, second layer L**2** of multi-layer surface coating **70** can indicate a "worn" wear level of packing **29** and/or coated substrate **55**, and first layer L**1** of multi-layer surface coating **70** can indicate an "unacceptably worn" wear level of packing **29** and/or coated substrate **55**. This can be considered similar to a stoplight indicator, with an initially outermost layer (e.g., L**4**) of multi-layer surface coating **70** indicating "green" or "continue" status, a layer (e.g., L**3**) initially located just below the outermost layer (e.g., L**4**) of multi-layer surface coating **70** indicating "orange" or "continue but be prepared to replace packing **29** and/or coated substrate **55**" status, and a layer (e.g., L**2**) initially located just below the second-outermost layer (e.g., L**3**) of multi-layer surface coating **70** indicating "red" or "replace packing **29** and/or coated substrate **55**" status. A plethora of combinations of layers can be utilized to indicate specific wear levels of packing **29** and/or coated substrate **55**. Inspection of the coated substrate, as described above (e.g., visual and/or other examination method(s)) can be utilized to determine which layer is now exposed (i.e., likewise which layer(s) have worn off), and thus determine the status of the wear level of the coated substrate **55** and/or the packing **29**. Thus, an initial thickness T_i of each of the plurality of wear layers L can be chosen based on a wear profile (e.g., wear depth allowances) of reciprocating element packing **29** and/or of the coated substrate **55**.

Without limitation, each layer of the plurality of layers L can be disposed by a technique independently selected (i.e., the technique utilized to dispose each layer can be the same or different from a technique utilized to dispose one or more other layer(s) of the multi-layer surface coating **70**) from high velocity oxygen fuel (HVOF), combustion flame spraying, plasma spraying, vacuum plasma spraying, two-wire electric arc spraying, or a combination thereof, in embodiments.

In embodiments, prior to disposing first layer L**1** in contact with contact surface **50**A of substrate **50** (e.g., outer surface **18**A of reciprocating element **18** and/or inner surface **95**A of sleeve **95** prior to any coating thereof) is ground, sanded, blasted, or otherwise roughened prior to disposing first layer L**1** thereupon, which may aid in the adherence of a first layer L**1** to a roughened outer surface of the substrate. Likewise, subsequent to disposing each layer of the plurality of layers L of multi-layer surface coating **70**, the substrate coated with the prior layer(s) can be ground, sanded, or otherwise roughened prior to disposing the subsequent layer thereupon, which may aid in the adherence of a subsequent coating to a prior coating. The grinding and/or other roughening can be utilized to provide a desired average thickness to the layer and/or promote disposal of the subsequent layer thereupon. In embodiments, one or more layers L of the plurality of layers of multi-layer surface coating **70** are disposed or applied to the substrate robotically, and no grinding or other mechanical treatment is needed subsequent disposal of the layer to provide the desired layer thickness (i.e., the robotic disposal/application provides a layer having the desired average thickness along central axis **17**A such that no further grinding or other mechanical treatment, except optionally a quick abrading to promote disposal and adherence of the subsequent layer, is utilized between disposal of each successive layer of the plurality of layers L. A final finish can be utilized subsequent disposal of the outermost layer (e.g., farthest from central axis **17**A of substrate

50 in a direction perpendicular thereto such as L2 of FIG. 6A or L4 of FIG. 6B) of multi-layer surface coating 70.

The pump fluid end 22 can be a pump fluid end 22 as described hereinabove with reference to FIGS. 2A-2B and FIG. 3. Pump fluid end 22 comprises a suction valve assembly 56 and a discharge valve assembly 72.

In embodiments, a discharge valve seat of discharge valve assembly 72 and/or a suction valve seat of suction valve assembly 56 is a valve seat with supplemental retention, as described, for example, in U.S. patent application Ser. No. 16/411,898 filed May 14, 2019, which is entitled "Pump Valve Seat with Supplemental Retention", the disclosure of which is hereby incorporated herein in its entirety for purposes not contrary to this disclosure.

In embodiments, suction valve assembly 56 and/or discharge valve assembly 72 comprises a valve assembly having a valve guide, as described, for example, in U.S. patent application Ser. No. 16/411,910 filed May 14, 2019, which is entitled "Valve Assembly for a Fluid End with Limited Access", the disclosure of which is hereby incorporated herein in its entirety for purposes not contrary to this disclosure.

In embodiments, suction valve assembly 56 of pump fluid end 22 comprises an easy access suction valve, as described, for example, in U.S. patent application Ser. No. 16/411,891 filed May 14, 2019, which is entitled "Pump Fluid End with Easy Access Suction Valve", the disclosure of which is hereby incorporated herein in its entirety for purposes not contrary to this disclosure.

In embodiments, pump fluid end 22 comprises a suction valve stop for assisting closure of suction valve assembly 56, as described, for example, in U.S. patent application Ser. No. 16/436,312 filed Jun. 10, 2019, and published as U.S. patent application Publication No. 2020/0386214 A1, which is entitled "Pump Fluid End with Suction Valve Closure Assist", the disclosure of which is hereby incorporated herein in its entirety for purposes not contrary to this disclosure.

In embodiments, suction valve assembly 56 and/or discharge valve assembly 72 of pump fluid end 22 comprises a valve poppet assembly, as described, for example, in U.S. patent application Ser. No. 16/436,356 filed Jun. 10, 2019, now U.S. Pat. No. 10,808,851B1, which is entitled "Multi-Material Frac Valve Poppet", the disclosure of which is hereby incorporated herein in its entirety for purposes not contrary to this disclosure.

Also disclosed herein is a pump 10 comprising: a pump fluid end 22 as described hereinabove; and a pump power end 12 (FIG. 1 and FIG. 4). The pump power end 12 is operable to reciprocate the reciprocating element 18 within the reciprocating element bore 24 (and optionally within sleeve 95 in embodiments comprising optional sleeve 95) of the pump fluid end 22. As described hereinabove, the reciprocating element 18 and/or the optional sleeve 95 comprise a coated substrate 55 (i.e., a coated reciprocating element 18 and/or a coated sleeve 95, respectively) having a multi-layer surface coating 70 of this disclosure disposed thereon.

In embodiments, pump 10 of this disclosure is a concentric bore pump fluid end 22 such as depicted in FIG. 3 and described hereinabove or a cross-bore pump fluid end such as depicted in FIG. 2A and FIG. 2B and described hereinabove. In embodiments, pump fluid end 22 comprises a reciprocating element 18 coupled with a suction valve assembly 56, such as the cross-bore (e.g., T-bore) pump fluid end 22 of FIG. 2B and the concentric bore pump fluid end 22 of FIG. 3. In some such embodiments, pump 10 further comprises a flexible manifold, as described, for example, in U.S. patent application Ser. No. 16/411,901 filed May 14, 2019, which is entitled "Flexible Manifold for Reciprocating Pump", the disclosure of which is hereby incorporated herein in its entirety for purposes not contrary to this disclosure.

Also disclosed herein is a method of indicating and/or determining the wear level of a reciprocating element packing 29 and/or the coated substrate 55 of a pump 10. The method comprises: coating at least a portion of an outer surface 18A of a cylindrical reciprocating element 18 and/or at least a portion of an inner surface 95A of a cylindrical sleeve 95 with a multi-layer surface coating 70 comprising a plurality of layers L. The coating includes disposing a first layer L1 in contact with the at least a portion of the outer surface 18A (e.g., the reciprocating element 19 comprising the contact surface 50A of the substrate 50) of the reciprocating element 18 and/or the at least a portion of the inner surface 95A (e.g., the sleeve 95 comprising the contact surface 50A of the substrate 50) of the sleeve 95, and disposing one or more additional layers (e.g., a second layer L2) over at least a portion of the first layer L1. The multi-layer surface coating 70 can comprise a desired total number of layers and can otherwise be as described in detail hereinabove. At least one of the plurality of layers L has a different visual appearance and/or material composition than at least one other of the plurality of layers L, and a thickness T_L of each layer of the plurality of layers L correlates with a level of wear of the reciprocating element packing 29 and/or coated substrate 55. The wear level of the pump 10 can be determined by examining the coated substrate 55 (e.g., the coated reciprocating element 18 and/or the coated sleeve 95), determining which layer (e.g., an innermost exposed layer) of the multi-layer surface coating 70 is exposed, and correlating the exposed layer (e.g., an innermost exposed layer) with a wear level of the packing 29 and/or the coated substrate 55.

As described herein, disposing each layer of the plurality of layers L of multi-layer coating 70 (e.g., disposing/applying the first layer L1, disposing/applying the second layer L2, disposing/applying the third layer L3, disposing/applying the fourth layer L4, and so on) can comprise disposing/applying via a technique independently selected from: high velocity oxygen fuel (HVOF), combustion flame spraying, plasma spraying, vacuum plasma spraying, two-wire electric arc spraying, or a combination thereof.

In embodiments, a rate of wear of packing 29 and/or coated substrate 55 is determined based on examination of the coated substrate 55 (e.g., the coated reciprocating element 18 and/or the coated sleeve 95). For example, a rate of wear of packing 29 and/or coated substrate 55 can be determined by correlating a rate of wear of the thickness T_C of coating 70 with a rate of wear of packing 29 and/or a rate of wear of coated substrate 55. In embodiments, the rate of wear of packing 29 and/or the rate of wear of coated substrate 55 can be utilized to predict when packing 29 and/or coated substrate 55 will be in need of repair and/or replacement.

As noted hereinabove, a pump 10 of this disclosure can be a multiplex pump comprising a plurality of reciprocating elements 18, and a corresponding plurality of reciprocating element bores 24, suction valve assemblies 56, discharge valve assemblies 72, and optional sleeves 95. The plurality can comprise any number such as, for example, 2, 3, 4, 5, 6, 7, or more. For example, in embodiments, pump 10 is a triplex pump, wherein the plurality comprises three. In alternative embodiments, pump **10** comprises a Quintuplex pump, wherein the plurality comprises five.

Also disclosed herein is a method of servicing a reciprocating pump **10** of this disclosure. The method comprises: inspecting a coated substrate located inside or proximate a reciprocating pump fluid end (e.g., an outer surface **18**A of a reciprocating element **18** of the pump **10** and/or an inner surface **95**A of a sleeve **95** positioned within a reciprocating element bore of the pump **10**), wherein said inspecting provides an indication of a level of wear of a component of the fluid end (e.g., a reciprocating element packing **29**, the sleeve **95**, and/or the reciprocating element **18**) of the pump **10**. The method of servicing the pump **10** further comprises: responsive to the indication of the level or wear of the fluid end component (e.g., reciprocating element packing **29**, the sleeve **95**, and/or the reciprocating element **18**), repairing or replacing the fluid end component (e.g., reciprocating element packing **29**, the sleeve **95**, and/or the reciprocating element **18**). As noted hereinabove, in embodiments, the indication of the level of wear comprises a presence of a particular color (e.g., a yellow color of an innermost exposed/visible layer) indicating wear of a coating **70** (e.g., outer layer L**2** of FIG. **6**A) on the outer surface **18**A of the reciprocating element **18** or wear of a coating **70** (e.g., outer layer L**2** of FIG. **6**A) on the inner surface **95**A of the sleeve **95**. For example, inspecting provides knowledge of what layer(s) (e.g., an innermost exposed layer that is detected/identified via inspection) of a multi-layer surface coating **70** are currently at least partially exposed (i.e., currently make up all or a portion of the outer surface **18**A of reciprocating element **18** and/or the inner surface **95**A of sleeve **95**), and the layer(s) currently exposed can be correlated with a specific wear level of a component of the fluid end such as the packing **29**, sleeve **95**, and/or reciprocating element **18**.

Also disclosed herein are a method of servicing a wellbore and a wellbore servicing system **200** comprising a pump of this disclosure. An embodiment of a wellbore servicing system **200** and a method of servicing a wellbore via the wellbore servicing system **200** will now be described with reference to FIG. **7**, which is a schematic representation of an embodiment of a wellbore servicing system **200**, according to embodiments of this disclosure.

A method of servicing a wellbore **224** according to this disclosure comprises: fluidly coupling a pump **10** of this disclosure to a source of a wellbore servicing fluid and to the wellbore; and communicating a wellbore servicing fluid into the wellbore via the pump **10**. As described hereinabove, the pump **10** comprises: a pump fluid end **22** and a pump power end **12**. The pump power end **12** is operable to reciprocate cylindrical reciprocating element **18** (which may or may not be coated with a multi-layer surface coating **70** of this disclosure) within a cylindrical reciprocating element bore **24** (and optionally within an optional sleeve **95** within reciprocating element bore **24**, which sleeve **95** may or may not be coated with a multi-layer surface coating **70** of this disclosure) of the pump fluid end **22**. The pump fluid end **22** comprises the reciprocating element **18** disposed at least partially within the reciprocating element bore **24** (and optionally within the optional sleeve **95** disposed within reciprocating element bore **24**), and the reciprocating element **18** has an outer surface **18**A. The pump fluid end **22** of pump **22** comprises a reciprocating element packing **29** positioned at a back S**2** (FIG. **1**, FIG. **2**A-**2**B, FIG. **3**, and FIG. **5**) of the pump fluid end **22** within the reciprocating element bore **24** (and optionally within optional sleeve **95** within reciprocating element bore **24**). The pump fluid end **22** of pump **10** optionally comprises a sleeve **95** positioned within the reciprocating element bore **24** such that the reciprocating element **18** reciprocates within the sleeve **95**. The optional sleeve has an inner surface **95**A proximate the outer surface **18**A of the reciprocating element **18**. As noted above, according to this disclosure, at least a portion of the outer surface **18**A of the reciprocating element **18** and/or at least a portion of the inner surface **95**A of the sleeve **95** comprises a multi-layer surface coating **70** comprising a plurality of layers L. The plurality of layers L include a first layer L**1** in contact with a contact surface **50**A comprising at least a portion of the outer surface **18**A of the reciprocating element **18** prior to coating thereof with multi-layer surface coating **70** and/or the at least a portion of the inner surface **95**A of the sleeve **95** prior to coating thereof with multi-layer surface coating **70**, and a second layer L**2** disposed over at least a portion of the first layer L**1**. At least one of the plurality of layers L has a different visual appearance and/or material composition than at least one other of the plurality of layers L.

In embodiments, the method of servicing the wellbore further comprises discontinuing the communicating of the wellbore servicing fluid into the wellbore via the pump **10**; examining the reciprocating element **18** and/or the sleeve **95** (which is/are coated with the multi-layer surface coating **70**) to ascertain a wear level of the reciprocating element packing **29**, the reciprocating element **18**, and/or the sleeve **95** based on a visual appearance and/or material composition of the (coated) reciprocating element **18** and/or the (coated) sleeve **95**. The method of servicing the wellbore can further comprise optionally subjecting the pump **10** to maintenance to provide a maintained pump **10**, wherein the maintenance comprises repairing or replacing the reciprocating element packing **29**, the sleeve **95**, and/or the reciprocating element. The method of servicing the wellbore can further comprise communicating the or another wellbore servicing fluid into the wellbore via the pump **10** or the maintained pump **10**.

It will be appreciated that the wellbore servicing system **200** disclosed herein can be used for any purpose. In embodiments, the wellbore servicing system **200** may be used to service a wellbore **224** that penetrates a subterranean formation by pumping a wellbore servicing fluid into the wellbore and/or subterranean formation. As used herein, a "wellbore servicing fluid" or "servicing fluid" refers to a fluid used to drill, complete, work over, fracture, repair, or in any way prepare a well bore for the recovery of materials residing in a subterranean formation penetrated by the well bore. It is to be understood that "subterranean formation" encompasses both areas below exposed earth and areas below earth covered by water such as ocean or fresh water. Examples of servicing fluids suitable for use as the wellbore servicing fluid, the another wellbore servicing fluid, or both include, but are not limited to, cementitious fluids (e.g., cement slurries), drilling fluids or muds, spacer fluids, fracturing fluids or completion fluids, and gravel pack fluids, remedial fluids, perforating fluids, diverter fluids, sealants, drilling fluids, completion fluids, gelation fluids, polymeric fluids, aqueous fluids, oleaginous fluids, etc.

In embodiments, the wellbore servicing system **200** comprises one or more pumps **10** operable to perform oilfield and/or well servicing operations. Such operations may include, but are not limited to, drilling operations, fracturing operations, perforating operations, fluid loss operations, primary cementing operations, secondary or remedial cementing operations, or any combination of operations thereof. Although a wellbore servicing system is illustrated, skilled artisans will readily appreciate that the pump **10** disclosed herein may be employed in any suitable operation.

In embodiments, the wellbore servicing system **200** may be a system such as a fracturing spread for fracturing wells in a hydrocarbon-containing reservoir. In fracturing operations, wellbore servicing fluids, such as particle laden fluids, are pumped at high-pressure into a wellbore. The particle laden fluids may then be introduced into a portion of a subterranean formation at a sufficient pressure and velocity to cut a casing and/or create perforation tunnels and fractures within the subterranean formation. Proppants, such as grains of sand, are mixed with the wellbore servicing fluid to keep the fractures open so that hydrocarbons may be produced from the subterranean formation and flow into the wellbore. Hydraulic fracturing may desirably create high-conductivity fluid communication between the wellbore and the subterranean formation.

The wellbore servicing system **200** comprises a blender **202** that is coupled to a wellbore services manifold trailer **204** via flowline **206**. As used herein, the term "wellbore services manifold trailer" includes a truck and/or trailer comprising one or more manifolds for receiving, organizing, and/or distributing wellbore servicing fluids during wellbore servicing operations. In this embodiment, the wellbore services manifold trailer **204** is coupled to six positive displacement pumps (e.g., such as pump **10** that may be mounted to a trailer and transported to the wellsite via a semi-tractor) via outlet flowlines **208** and inlet flowlines **210**. In alternative embodiments, however, there may be more or less pumps used in a wellbore servicing operation. Outlet flowlines **208** are outlet lines from the wellbore services manifold trailer **204** that supply fluid to the pumps **10**. Inlet flowlines **210** are inlet lines from the pumps **10** that supply fluid to the wellbore services manifold trailer **204**.

The blender **202** mixes solid and fluid components to achieve a well-blended wellbore servicing fluid. As depicted, sand or proppant **212**, water **214**, and additives **216** are fed into the blender **202** via feedlines **218**, **220**, and **212**, respectively. The water **214** may be potable, non-potable, untreated, partially treated, or treated water. In embodiments, the water **214** may be produced water that has been extracted from the wellbore while producing hydrocarbons form the wellbore. The produced water may comprise dissolved and/or entrained organic materials, salts, minerals, paraffins, aromatics, resins, asphaltenes, and/or other natural or synthetic constituents that are displaced from a hydrocarbon formation during the production of the hydrocarbons. In embodiments, the water **214** may be flowback water that has previously been introduced into the wellbore during wellbore servicing operation. The flowback water may comprise some hydrocarbons, gelling agents, friction reducers, surfactants and/or remnants of wellbore servicing fluids previously introduced into the wellbore during wellbore servicing operations.

The water **214** may further comprise local surface water contained in natural and/or manmade water features (such as ditches, ponds, rivers, lakes, oceans, etc.). Still further, the water **214** may comprise water stored in local or remote containers. The water **214** may be water that originated from near the wellbore and/or may be water that has been transported to an area near the wellbore from any distance. In some embodiments, the water **214** may comprise any combination of produced water, flowback water, local surface water, and/or container stored water. In some implementations, water may be substituted by nitrogen or carbon dioxide; some in a foaming condition.

In embodiments, the blender **202** may be an Advanced Dry Polymer (ADP) blender and the additives **216** are dry blended and dry fed into the blender **202**. In alternative embodiments, however, additives may be pre-blended with water using other suitable blenders, such as, but not limited to, a GEL PRO blender, which is a commercially available preblender trailer from Halliburton Energy Services, Inc., to form a liquid gel concentrate that may be fed into the blender **202**. The mixing conditions of the blender **202**, including time period, agitation method, pressure, and temperature of the blender **202**, may be chosen by one of ordinary skill in the art with the aid of this disclosure to produce a homogeneous blend having a desirable composition, density, and viscosity. In alternative embodiments, however, sand or proppant, water, and additives may be premixed and/or stored in a storage tank before entering a wellbore services manifold trailer **204**.

In embodiments, the pump(s) **10** (e.g., pump(s) **10** and/or maintained pump(s) **10**) pressurize the wellbore servicing fluid to a pressure suitable for delivery into a wellbore **224** or wellhead. For example, the pumps **10** may increase the pressure of the wellbore servicing fluid (e.g., the wellbore servicing fluid and/or the another wellbore servicing fluid) to a pressure of greater than or equal to about 3,000 psi, 5,000 psi, 10,000 psi, 20,000 psi, 30,000 psi, 40,000 psi, or 50,000 psi, or higher.

From the pumps **10**, the wellbore servicing fluid may reenter the wellbore services manifold trailer **204** via inlet flowlines **210** and be combined so that the wellbore servicing fluid may have a total fluid flow rate that exits from the wellbore services manifold trailer **204** through flowline **226** to the flow connector wellbore **1128** of between about 1 BPM to about 200 BPM, alternatively from between about 50 BPM to about 150 BPM, alternatively about 100 BPM. In embodiments, each of one or more pumps **10** discharge wellbore servicing fluid at a fluid flow rate of between about 1 BPM to about 200 BPM, alternatively from between about 50 BPM to about 150 BPM, alternatively about 100 BPM. In embodiments, each of one or more pumps **10** discharge wellbore servicing fluid at a volumetric flow rate of greater than or equal to about 3, 10, or 20 barrels per minute (BPM), or in a range of from about 3 to about 20, from about 10 to about 20, or from about 5 to about 20 BPM.

Persons of ordinary skill in the art with the aid of this disclosure will appreciate that the flowlines described herein are piping that are connected together for example via flanges, collars, welds, etc. These flowlines may include various configurations of pipe tees, elbows, and the like. These flowlines connect together the various wellbore servicing fluid process equipment described herein.

Also disclosed herein are methods for servicing a wellbore (e.g., wellbore **224**). Without limitation, servicing the wellbore may include: positioning the wellbore servicing composition in the wellbore **224** (e.g., via one or more pumps **10** as described herein) to isolate the subterranean formation from a portion of the wellbore; to support a conduit in the wellbore; to plug a void or crack in the conduit; to plug a void or crack in a cement sheath disposed in an annulus of the wellbore; to plug a perforation; to plug an opening between the cement sheath and the conduit; to prevent the loss of aqueous or nonaqueous drilling fluids into loss circulation zones such as a void, vugular zone, or fracture; to plug a well for abandonment purposes; to divert treatment fluids; and/or to seal an annulus between the wellbore and an expandable pipe or pipe string. In other embodiments, the wellbore servicing systems and methods may be employed in well completion operations such as primary and secondary cementing operation to isolate the subterranean formation from a different portion of the wellbore.

In embodiments, a wellbore servicing method may comprise transporting a positive displacement pump (e.g., pump **10**) to a site for performing a servicing operation. Additionally or alternatively, one or more pumps may be situated on a suitable structural support. Non-limiting examples of a suitable structural support or supports include a trailer, truck, skid, barge or combinations thereof. In embodiments, a motor or other power source for a pump may be situated on a common structural support.

In embodiments, a wellbore servicing method may comprise providing a source for a wellbore servicing fluid. As described above, the wellbore servicing fluid may comprise any suitable fluid or combinations of fluid as may be appropriate based upon the servicing operation being performed. Non-limiting examples of suitable wellbore servicing fluid include a fracturing fluid (e.g., a particle laden fluid, as described herein), a perforating fluid, a cementitious fluid, a sealant, a remedial fluid, a drilling fluid (e.g., mud), a spacer fluid, a gelation fluid, a polymeric fluid, an aqueous fluid, an oleaginous fluid, an emulsion, various other wellbore servicing fluid as will be appreciated by one of skill in the art with the aid of this disclosure, and combinations thereof. The wellbore servicing fluid may be prepared on-site (e.g., via the operation of one or more blenders) or, alternatively, transported to the site of the servicing operation.

In embodiments, a wellbore servicing method may comprise fluidly coupling a pump **10** to the wellbore servicing fluid source. As such, wellbore servicing fluid may be drawn into and emitted from the pump **10**. Additionally or alternatively, a portion of a wellbore servicing fluid placed in a wellbore **224** may be recycled, i.e., mixed with the water stream obtained from a water source and treated in fluid treatment system. Furthermore, a wellbore servicing method may comprise conveying the wellbore servicing fluid from its source to the wellbore via the operation of the pump **10** disclosed herein.

In alternative embodiments, the reciprocating apparatus may comprise a compressor. In embodiments, a compressor similar to the pump **10** may comprise at least one each of a cylinder, plunger, connecting rod, crankshaft, and housing, and may be coupled to a motor. In embodiments, such a compressor may be similar in form to a pump and may be configured to compress a compressible fluid (e.g., a gas) and thereby increase the pressure of the compressible fluid. For example, a compressor may be configured to direct the discharge therefrom to a chamber or vessel that collects the compressible fluid from the discharge of the compressor until a predetermined pressure is built up in the chamber. Generally, a pressure sensing device may be arranged and configured to monitor the pressure as it builds up in the chamber and to interact with the compressor when a predetermined pressure is reached. At that point, the compressor may either be shut off, or alternatively the discharge may be directed to another chamber for continued operation.

In embodiments, a reciprocating apparatus comprises an internal combustion engine, hereinafter referred to as an engine. Such engines are also well known, and typically include at least one each of a plunger, cylinder, connecting rod, and crankshaft. The arrangement of these components is substantially the same in an engine and a pump (e.g. pump **10**). A reciprocating element **18** such as a plunger may be similarly arranged to move in reciprocating fashion within the cylinder. Skilled artisans will appreciate that operation of an engine may somewhat differ from that of a pump. In a pump, rotational power is generally applied to a crankshaft acting on the plunger via the connecting rod, whereas in an engine, rotational power generally results from a force (e.g., an internal combustion) exerted on or against the plunger, which acts against the crankshaft via the connecting rod.

For example, in a typical 4-stroke engine, arbitrarily beginning with the exhaust stroke, the plunger is fully extended during the exhaust stroke, (e.g., minimizing the internal volume of the cylinder). The plunger may then be retracted by inertia or other forces of the engine componentry during the intake stroke. As the plunger retracts within the cylinder, the internal volume of cylinder increases, creating a low pressure within the cylinder into which an air/fuel mixture is drawn. When the plunger is fully retracted within the cylinder, the intake stroke is complete, and the cylinder is substantially filled with the air/fuel mixture. As the crankshaft continues to rotate, the plunger may then be extended, during the compression stroke, into the cylinder compressing the air-fuel mixture within the cylinder to a higher pressure.

A spark plug may be provided to ignite the fuel at a predetermined point in the compression stroke. This ignition increases the temperature and pressure within the cylinder substantially and rapidly. In a diesel engine, however, the spark plug may be omitted, as the heat of compression derived from the high compression ratios associated with diesel engines suffices to provide spontaneous combustion of the air-fuel mixture. In either case, the heat and pressure act forcibly against the plunger and cause it to retract back into the cylinder during the power cycle at a substantial force, which may then be exerted on the connecting rod, and thereby on to the crankshaft.

Those of ordinary skill in the art will readily appreciate various benefits that may be realized by the present disclosure. For instance, the herein disclosed fluid end design **22** comprising a multi-layer surface coating **70** indicative of a wear level of a component of the fluid end such as packing **29**, a sleeve **95**, and/or a reciprocating element **18** can facilitate determination of whether or not the fluid end component (e.g., a packing **29**, a sleeve **95**, and/or a reciprocating element **18**) needs replacement and/or repair. The rate of wear of the fluid end component (e.g., packing **29**, sleeve **95**, and/or reciprocating element **18**) can be calculated based on the rate at which the multi-layer coating **70** wears, and the rate of wear of the fluid end component (e.g., packing **29**, sleeve **95**, and/or reciprocating element **18**) can be utilized to predict when the fluid end component (e.g., packing **29**, sleeve **95**, and/or reciprocating element **18**) will need servicing (e.g., repair and/or replacement). Accordingly, a multi-layer surface coating **70** of this disclosure can be utilized to facilitate maintenance of a pump fluid end comprising a fluid end component substrate (e.g., an outer surface of reciprocating element **18** and/or an inner surface of packing sleeve **95**) having the multi-layer surface coating disposed thereon. Use of the multi-layer surface coating **70** of this disclosure can reduce or minimize over-use or under-use replacement fluid end components such as of sleeves **95** and/or reciprocating elements **18**, increase or maximize a life of packing **29**, and/or reduce or minimize time lost due to out of service pumps **10**.

Additional Disclosure

The following are non-limiting, specific embodiments in accordance with the present disclosure:

Embodiment A: A pump fluid end comprising: a cylindrical reciprocating element disposed at least partially within a cylindrical reciprocating element bore and having an outer surface; a reciprocating element packing positioned within the reciprocating element bore (e.g., at a back of the pump fluid end); and optionally a cylindrical sleeve positioned within the reciprocating element bore such that the reciprocating element reciprocates within the sleeve and having an inner surface proximate the outer surface of the reciprocating element, wherein at least a portion of the outer surface of the reciprocating element and/or at least a portion of the inner surface of the sleeve is coated with a multi-layer surface coating comprising a plurality of layers including: a first layer in contact with the at least a portion of the outer surface of the reciprocating element and/or the at least a portion of the inner surface of the sleeve; and a second layer disposed over at least a portion of the first layer; and wherein at least one of the plurality of layers has a different visual appearance and/or material composition than at least one other of the plurality of layers.

Embodiment B: The pump fluid end of Embodiment A, wherein the multilayer surface coating consists of the first layer and the second layer, and wherein the first layer has a different visual appearance and/or material composition than the second layer.

Embodiment C: The pump fluid end of Embodiment A or Embodiment B, wherein a color of the second layer is different from a color of the first layer.

Embodiment D: The pump fluid end of Embodiment C, wherein the color of the first layer is yellow.

Embodiment E: The pump fluid end of any of Embodiment A through Embodiment D, wherein the multilayer surface coating further comprises a third layer.

Embodiment F: The pump fluid end of any of Embodiment A through Embodiment E, wherein the first layer and/or the second layer has a thickness in a range of from about 0.01 to about 0.04 inch (from about 254 to about 1016 μm), from about 0.01 to about 0.03 inch (from about 254 to about 762 μm), from about 0.01 to about 0.02 inch (from about 254 to about 508 μm), or less than or equal to about 0.04 inch (1016 μm), 0.03 inch (762 μm), 0.02 inch (508 μm), or 0.01 inch (254 μm).

Embodiment G: The pump fluid end of any of Embodiment A through Embodiment F, wherein each layer of the plurality of layers has a thickness in a range of from about 0.01 to about 0.04 inch (from about 254 to about 1016 μm), from about 0.01 to about 0.03 inch (from about 254 to about 762 μm), from about 0.01 to about 0.02 inch (from about 254 to about 508 μm), or less than or equal to about 0.04 inch (1016 μm), 0.03 inch (762 μm), 0.02 inch (508 μm), or 0.01 inch (254 μm).

Embodiment H: The pump fluid end of any of Embodiment A through Embodiment G, wherein the multilayer surface coating has a thickness in a range of from about 0.01 to about 0.04 inch (from about 254 to about 1016 μm), from about 0.01 to about 0.03 inch (from about 254 to about 762 μm), from about 0.01 to about 0.02 inch (from about 254 to about 508 μm), or less than or equal to about 0.04 inch (1016 μm), 0.03 inch (762 μm), 0.02 inch (508 μm), or 0.01 inch (254 μm).

Embodiment I: The pump fluid end of any of Embodiment A through Embodiment H, wherein the at least a portion of the outer surface of the reciprocating element comprises the multilayer surface coating.

Embodiment J: The pump fluid end of any of Embodiment A through Embodiment I, wherein the at least a portion of the inner surface of the sleeve comprises the multilayer surface coating.

Embodiment K: The pump fluid end of any of Embodiment A through Embodiment J, wherein the first layer comprises a nickel-based spray layer, iron particles, an aluminum bronze layer, or a combination thereof.

Embodiment L: The pump fluid end of any of Embodiment A through Embodiment K, wherein the second layer comprises titanium, ceramic alumina, a nickel-based spray, iron particles, or a combination thereof that is different from the first layer.

Embodiment M: The pump fluid end of any of Embodiment A through Embodiment L, wherein the visual appearance and/or material composition of each layer of the plurality of layers indicates a condition (e.g., a specific wear level) of the packing, the coated reciprocating element, and/or the coated sleeve.

Embodiment N: The pump fluid end of any of Embodiment A through Embodiment M, wherein an initial thickness of the second layer is equal to a maximum wear allowance of the packing, the coated reciprocating element, and/or the coated sleeve.

Embodiment O: The pump fluid end of any of Embodiment A through Embodiment N, wherein the first layer and/or the second layer independently comprises a high velocity oxygen fuel (HVOF) layer, a combustion flame spray layer, a plasma spray layer, a vacuum plasma spray layer, a two wire electric arc spray layer, or a combination thereof.

Embodiment P: The pump fluid end of any of Embodiment A through Embodiment O, wherein each layer of the plurality of layers independently comprises a nickel-based spray layer, a titanium nitride layer, a ceramic alumina layer, an alumina bronze layer, or a combination thereof.

Embodiment Q: A pump comprising: the pump fluid end of any of Embodiment A through Embodiment P; and a pump power end, wherein the pump power end is operable to reciprocate the reciprocating element within the reciprocating element bore of the pump fluid end.

Embodiment R: A method of servicing a wellbore, the method comprising: fluidly coupling a pump to a source of a wellbore servicing fluid and to the wellbore; and communicating a wellbore servicing fluid into the wellbore via the pump, wherein the pump comprises: a pump fluid end and a pump power end, wherein the pump power end is operable to reciprocate a cylindrical reciprocating element within a cylindrical reciprocating element bore of the pump fluid end, and wherein the pump fluid end comprises: the reciprocating element disposed at least partially within the reciprocating element bore and having an outer surface; a reciprocating element packing positioned at a back of the pump fluid end within the reciprocating element bore; and optionally a sleeve positioned within the reciprocating element bore such that the reciprocating element reciprocates within the sleeve and having an inner surface proximate the outer surface of the reciprocating element, wherein at least a portion of the outer surface of the reciprocating element comprises a multi-layer surface coating and the reciprocating element is a coated reciprocating element and/or wherein at least a portion of the inner surface of the sleeve comprises a multi-layer surface coating and the sleeve is a coated sleeve, wherein the multi-layer surface coating comprises a plurality of layers including: a first layer in contact with the at least a portion of the outer surface of the reciprocating element and/or the at least a portion of the inner surface of the sleeve; and a second layer disposed over at least a portion of the first layer; and wherein at least one of the plurality of layers has a different visual appearance and/or material composition than at least one other of the plurality of layers.

Embodiment S: The method of Embodiment R further comprising: discontinuing the communicating of the wellbore servicing fluid into the wellbore via the pump; examining the coated reciprocating element and/or the coated sleeve to ascertain a wear level of the reciprocating element packing, the coated reciprocating element, and/or the coated sleeve based on a visual appearance and/or material composition of the coated reciprocating element and/or the coated sleeve; optionally subjecting the pump to maintenance to provide a maintained pump, wherein the maintenance comprises repairing or replacing the reciprocating element packing, the reciprocating element, and/or the sleeve; and communicating the or another wellbore servicing fluid into the wellbore via the pump or the maintained pump.

Embodiment T: The method of Embodiment R or Embodiment S, wherein the wellbore servicing fluid, the another wellbore servicing fluid, or both the wellbore servicing fluid and the another wellbore servicing fluid comprise a fracturing fluid, a cementitious fluid, a remedial fluid, a perforating fluid, a sealant, a drilling fluid, a spacer fluid, a completion fluid, a gravel pack fluid, a gelation fluid, a polymeric fluid, an aqueous fluid, an oleaginous fluid, or a combination thereof.

Embodiment U: The method of any of Embodiment R through Embodiment T, wherein the pump or the maintained pump operates during the pumping of the wellbore servicing fluid or the another wellbore servicing fluid at a pressure of greater than or equal to about 3,000 psi, 5,000 psi, 10,000 psi, 20,000 psi, 30,000 psi, 40,000 psi, or 50,000 psi.

Embodiment V: The method of any of Embodiment R through Embodiment U, wherein the pump or the maintained pump operates during the pumping of the wellbore servicing fluid or the another wellbore servicing fluid at a volumetric flow rate of greater than or equal to about 3, 10, or 20 barrels per minute (BPM), or in a range of from about 3 to about 20, from about 10 to about 20, or from about 5 to about 20 BPM.

Embodiment W: A method of indicating the wear level of a reciprocating element packing of a pump, the method comprising: coating at least a portion of an outer surface of a cylindrical reciprocating element or at least a portion of an inner surface of a cylindrical sleeve with a multi-layer surface coating comprising a plurality of layers by: disposing a first layer in contact with the at least a portion of the outer surface of the reciprocating element to provide a coated reciprocating element and/or the at least a portion of the inner surface of the sleeve to provide a coated sleeve; and disposing a second layer over at least a portion of the first layer, wherein at least one of the plurality of layers has a different visual appearance and/or material composition than at least one other of the plurality of layers, and wherein a thickness of each of the plurality of layers correlates with a level of wear of the reciprocating element packing, the coated reciprocating element, and/or the coated sleeve.

Embodiment X: The method of Embodiment W, wherein disposing the first layer and/or disposing the second layer comprises disposing via: high velocity oxygen fuel (HVOF), combustion flame spraying, plasma spraying, vacuum plasma spraying, two-wire electric arc spraying, or a combination thereof.

Embodiment Y: A method of servicing a reciprocating pump comprising: inspecting an outer surface of a reciprocating element of the pump and/or an inner surface of a sleeve positioned within a reciprocating element bore of the pump, wherein said inspecting provides an indication of a level of wear of a reciprocating element packing of the pump; and responsive to the indication of a level or wear of the reciprocating element packing, repairing or replacing the reciprocating element packing.

Embodiment Z: The method of Embodiment Y, wherein the indication of a level of wear comprises a presence of a particular color indicating wear of a coating on the outer surface of the reciprocating element or wear of a coating on the inner surface of the sleeve.

While embodiments have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit and teachings of this disclosure. The embodiments described herein are exemplary only, and are not intended to be limiting. Many variations and modifications of the embodiments disclosed herein are possible and are within the scope of this disclosure. Where numerical ranges or limitations are expressly stated, such express ranges or limitations should be understood to include iterative ranges or limitations of like magnitude falling within the expressly stated ranges or limitations (e.g., from about 1 to about 10 includes, 2, 3, 4, etc.; greater than 0.10 includes 0.11, 0.12, 0.13, etc.). For example, whenever a numerical range with a lower limit, R**1**, and an upper limit, Ru, is disclosed, any number falling within the range is specifically disclosed. In particular, the following numbers within the range are specifically disclosed: R=R**1**+k*(Ru−R**1**), wherein k is a variable ranging from 1 percent to 100 percent with a 1 percent increment, i.e., k is 1 percent, 2 percent, 3 percent, 4 percent, 5 percent, . . . 50 percent, 51 percent, 52 percent, . . . , 95 percent, 96 percent, 97 percent, 98 percent, 99 percent, or 100 percent. Moreover, any numerical range defined by two R numbers as defined in the above is also specifically disclosed. Use of the term "optionally" with respect to any element of a claim is intended to mean that the subject element is required, or alternatively, is not required. Both alternatives are intended to be within the scope of the claim. Use of broader terms such as comprises, includes, having, etc. should be understood to provide support for narrower terms such as consisting of, consisting essentially of, comprised substantially of, etc.

Accordingly, the scope of protection is not limited by the description set out above but is only limited by the claims which follow, that scope including all equivalents of the subject matter of the claims. Each and every claim is incorporated into the specification as an embodiment of the present disclosure. Thus, the claims are a further description and are an addition to the embodiments of the present disclosure. The discussion of a reference herein is not an admission that it is prior art, especially any reference that may have a publication date after the priority date of this application. The disclosures of all patents, patent applications, and publications cited herein are hereby incorporated by reference, to the extent that they provide exemplary, procedural, or other details supplementary to those set forth herein.

We claim:

1. A pump fluid end comprising:

a cylindrical reciprocating element disposed at least partially within a cylindrical reciprocating element bore and having an outer surface extending along a length thereof;

a reciprocating element packing positioned within the reciprocating element bore; and

optionally a cylindrical sleeve positioned within the reciprocating element bore such that the reciprocating element reciprocates within the sleeve and having an inner surface proximate the outer surface of the reciprocating element, wherein at least a portion of the outer surface extending along the length of the reciprocating element is coated with a multi-layer surface coating comprising a plurality of layers including:

a first layer in contact with the at least a portion of the outer surface of the reciprocating element; and

a second layer disposed over at least a portion of the first layer; and

wherein at least one of the plurality of layers has a different visual appearance than at least one other of the plurality of layers, and wherein an initial thickness of each layer of the plurality of layers indicates a specific level of wear of the reciprocating element packing and/or the coated reciprocating element, such that visual examination of the coated reciprocating element disposed at least partially within the cylindrical reciprocating element bore can be utilized to determine a level of wear of the reciprocating element packing and/or the coated reciprocating element resulting from operation of the pump fluid end.

2. The pump fluid end of claim **1**, wherein the multilayer surface coating consists of the first layer and the second layer, and wherein the first layer further has a different material composition than the second layer.

3. The pump fluid end of claim **2**, wherein a color of the second layer is different from a color of the first layer.

4. The pump fluid end of claim **3**, wherein the color of the first layer is yellow.

5. The pump fluid end of claim **1**, wherein the multilayer surface coating further comprises a third layer.

6. The pump fluid end of claim **1**, wherein the first layer, the second layer, each of the plurality of layers, and/or the multilayer surface coating has a thickness of less than or equal to about 0.04 inch (1016 μm).

7. The pump fluid end of claim **1**, wherein the entire outer surface of the reciprocating element comprises the multi-layer surface coating.

8. The pump fluid end of claim **1**, comprising the cylindrical sleeve, wherein least a portion of the inner surface of the cylindrical sleeve also comprises the multilayer surface coating.

9. The pump fluid end of claim **1**, wherein the first layer comprises a nickel-based spray layer, iron particles, an aluminum bronze layer, or a combination thereof.

10. The pump fluid end of claim **9**, wherein the second layer comprises titanium, ceramic alumina, a nickel-based spray, iron particles, or a combination thereof that is different from the first layer.

11. The pump fluid end of claim **1**, wherein an initial thickness of the second layer is equal to a maximum wear allowance of the packing and/or the coated reciprocating element.

12. The pump fluid end of claim **1**, wherein the first layer and/or the second layer independently comprises a high velocity oxygen fuel (HVOF) layer, a combustion flame spray layer, a plasma spray layer, a vacuum plasma spray layer, a two wire electric arc spray layer, or a combination thereof.

13. The pump fluid end of claim **1**, wherein each layer of the plurality of layers independently comprises a nickel-based spray layer, a titanium nitride layer, a ceramic alumina layer, an alumina bronze layer, or a combination thereof.

14. A method of servicing a wellbore, the method comprising:

fluidly coupling a pump to a source of a wellbore servicing fluid and to the wellbore; and

communicating a wellbore servicing fluid into the wellbore via the pump,

wherein the pump comprises:

a pump fluid end and a pump power end,

wherein the pump power end is operable to reciprocate a cylindrical reciprocating element within a cylindrical reciprocating element bore of the pump fluid end, and

wherein the pump fluid end comprises: the reciprocating element disposed at least partially within the reciprocating element bore and having an outer surface extending along a length thereof;

a reciprocating element packing positioned at a back of the pump fluid end within the reciprocating element bore; and optionally a sleeve positioned within the reciprocating element bore such that the reciprocating element reciprocates within the sleeve and having an inner surface proximate the outer surface of the reciprocating element,

wherein at least a portion of the outer surface extending along the length of the reciprocating element comprises a multi-layer surface coating and the reciprocating element is a coated reciprocating element, wherein the multi-layer surface coating comprises a plurality of layers including: a first layer in contact with the at least a portion of the outer surface of the reciprocating element; and a second layer disposed over at least a portion of the first layer; and

wherein at least one of the plurality of layers has a different visual appearance than at least one other of the plurality of layers, and wherein an initial thickness of each layer of the plurality of layers indicates a specific level of wear of the reciprocating element packing and/or the coated reciprocating element, such that visual examination of the coated reciprocating element disposed at least partially within the cylindrical reciprocating element bore can be utilized to determine a level of wear of the reciprocating element packing and/or the coated reciprocating element resulting from operation of the pump fluid end.

15. The method of claim **14** further comprising:

discontinuing the communicating of the wellbore servicing fluid into the wellbore via the pump;

examining the coated reciprocating element disposed at least partially within the cylindrical reciprocating element bore to ascertain a wear level of the reciprocating element packing and/or the coated reciprocating element based on a visual appearance of the coated reciprocating element;

optionally subjecting the pump to maintenance to provide a maintained pump, wherein the maintenance comprises repairing or replacing the reciprocating element packing, the reciprocating element, and/or the cylindrical sleeve; and

communicating the or another wellbore servicing fluid into the wellbore via the pump or the maintained pump.

16. The method of claim **15**, wherein the wellbore servicing fluid, the another wellbore servicing fluid, or both the wellbore servicing fluid and the another wellbore servicing fluid comprise a fracturing fluid, a cementitious fluid, a remedial fluid, a perforating fluid, a sealant, a drilling fluid, a spacer fluid, a completion fluid, a gravel pack fluid, a gelation fluid, a polymeric fluid, an aqueous fluid, an oleaginous fluid, or a combination thereof.

17. The method of claim **15**, wherein the pump or the maintained pump operates during the pumping of the wellbore servicing fluid or the another wellbore servicing fluid at a pressure of greater than or equal to about 3,000 psi, 5,000 psi, 10,000 psi, 20,000 psi, 30,000 psi, 40,000 psi, or 50,000 psi.

18. The method of claim **15** wherein the pump or the maintained pump operates during the pumping of the wellbore servicing fluid or the another wellbore servicing fluid at a volumetric flow rate of greater than or equal to about 3, 10, or 20 barrels per minute (BPM), or in a range of from about 3 to about 20, from about 10 to about 20, or from about 5 to about 20 BPM.

19. A method of indicating the wear level of a reciprocating element packing of a pump, the method comprising:

coating at least a portion of an outer surface extending along a length of a cylindrical reciprocating element with a multi-layer surface coating comprising a plurality of layers by:

disposing a first layer in contact with the at least a portion of the outer surface extending along the length of the reciprocating element to provide a coated reciprocating element; and

disposing a second layer over at least a portion of the first layer,

wherein at least one of the plurality of layers has a different visual appearance than at least one other of the plurality of layers, and wherein a thickness of each of the plurality of layers correlates with a level of wear of the reciprocating element packing and/or the coated reciprocating element.

20. The method of claim **19**, wherein disposing the first layer and/or disposing the second layer comprises disposing via: high velocity oxygen fuel (HVOF), combustion flame spraying, plasma spraying, vacuum plasma spraying, two-wire electric arc spraying, or a combination thereof.

21. The pump fluid end of claim **1**, wherein a thickness of the first layer is selected to indicate a need for repair or replacement of the packing and/or the coated reciprocating element when the examination of the reciprocating element packing and/or the coated reciprocating element indicates that the first layer is exposed.

22. The pump fluid end of claim **1**, wherein examination further comprises ultrasonic inspection, magnetic field detection, eddy current, liquid penetrant, or a combination thereof.

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